Future short-baseline sterile neutrino searches with accelerators

Joshua Spitz, MIT
Neutrino 2014, 6/7/2014

Present status of the light sterile neutrino

- A number of experiments hint at a new neutrino mass eigenstate around 1 eV.

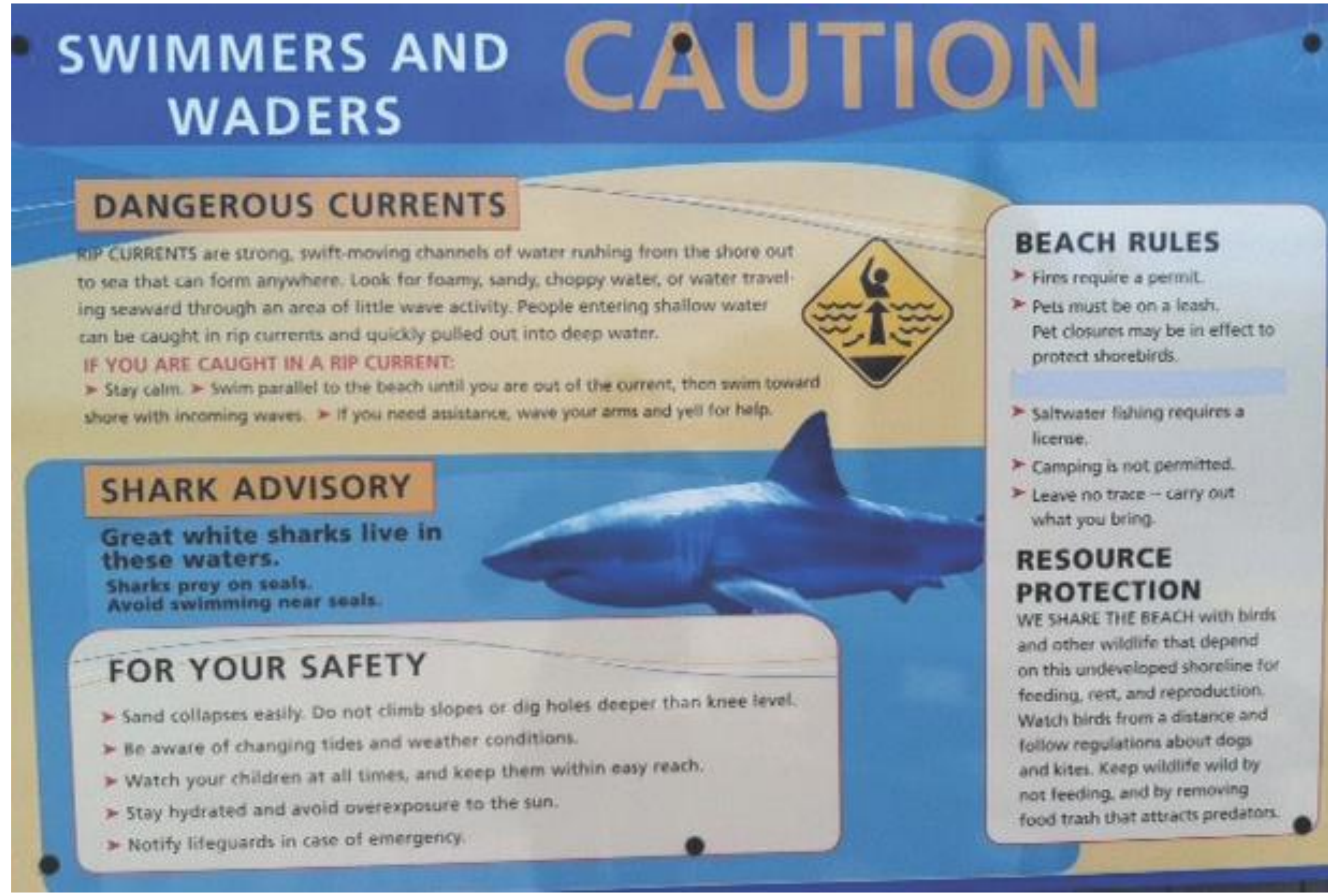
- A definitive probe of this parameter space is necessary.

- It would be great if the solution we develop could be used toward the future (e.g. δ_{CP}).

3 neutrino
oscillation framework

Light sterile neutrino
(or something else
we don't understand)

“JAWS” (1975)
Directed by Steven Spielberg



From Cape Cod, Massachusetts (~70 miles away)

My charge

From G. Feldman:

I would like to invite you to give a critical review talk on future short baseline experiments at the 26th International Conference on Neutrino Physics and Astrophysics (Neutrino 2014)…

By short baseline, I mean the search for sterile neutrinos whose masses are well above the atmospheric mass scale. There appear to be many different proposals. I see one of main functions of this talk is to clarify which can be conclusive in confirming or refuting the present anomalies.

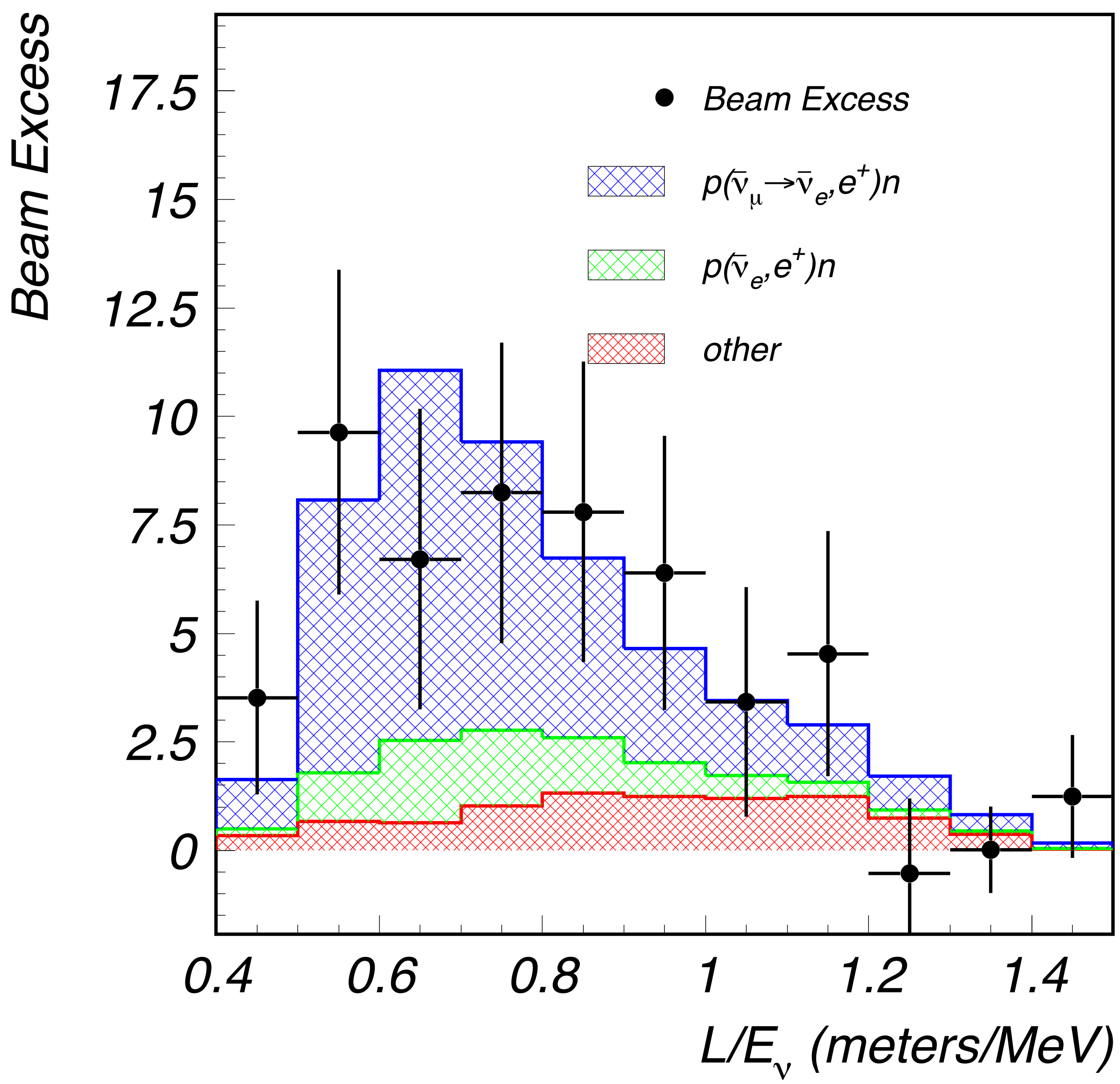
(emphasis is mine)

Outline

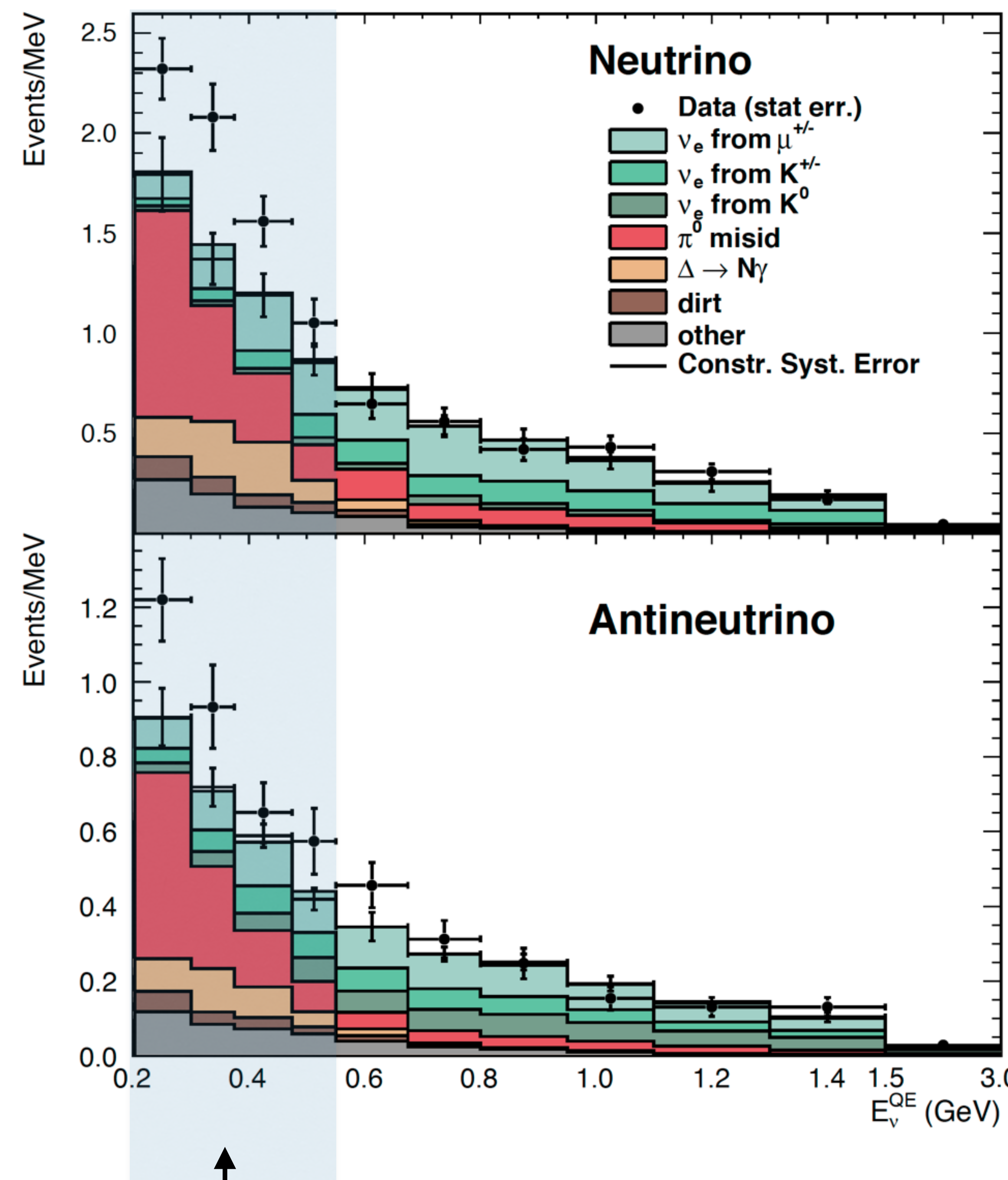
- Where are we with the sterile neutrino?
- Sterile neutrino complications and complaints.
- What do we need to do to solve the light sterile neutrino issue?
- An overview of the future accelerator-based experiments in the field.

Signal(?)

LSND

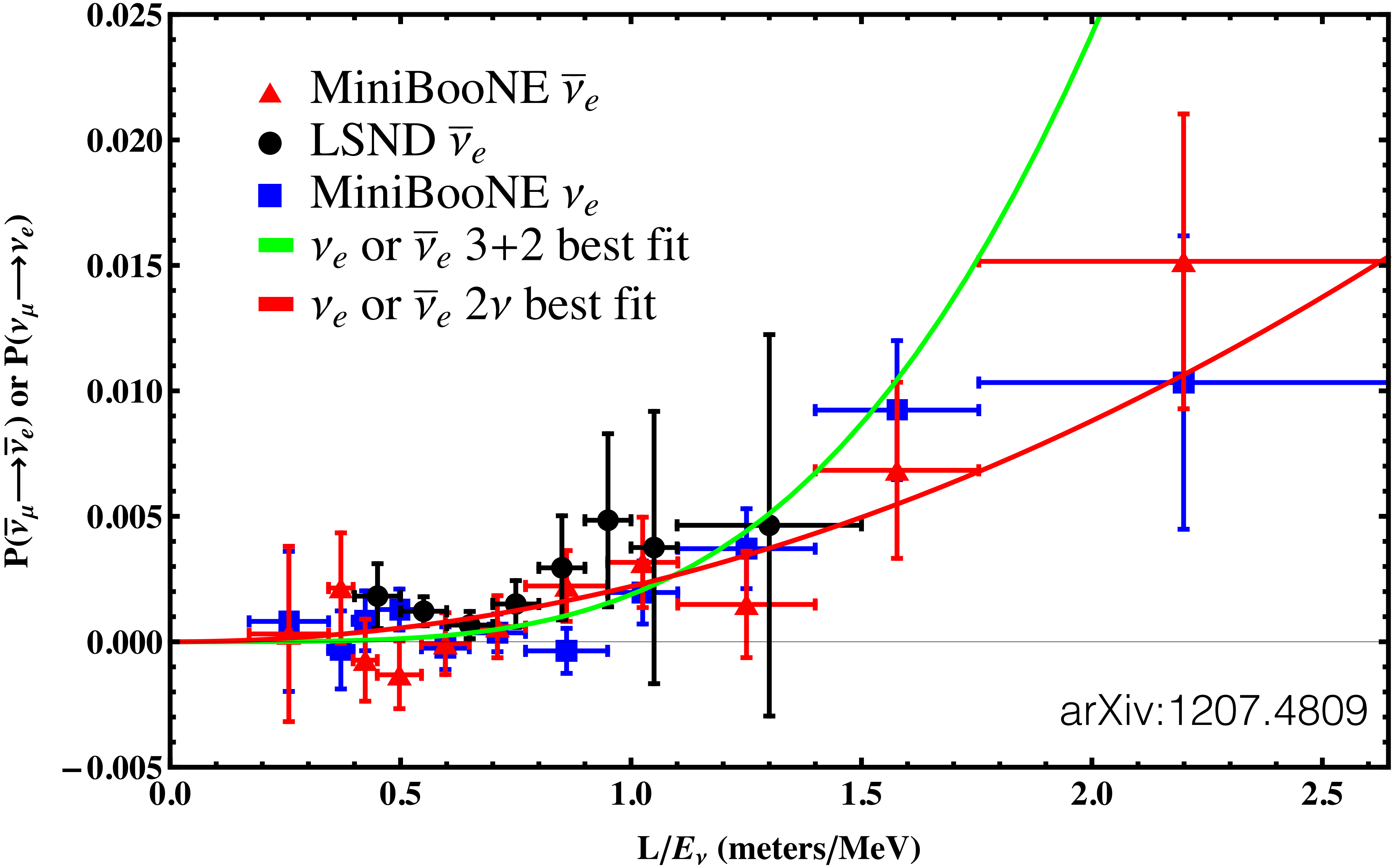


MiniBooNE



The “low energy excess”

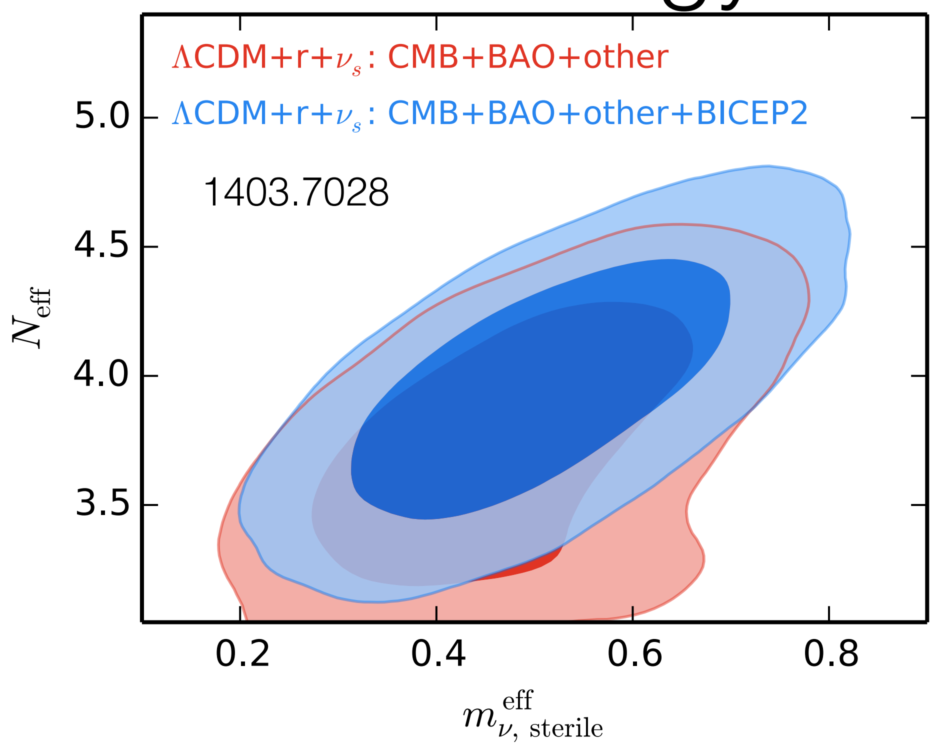
Signal(?)



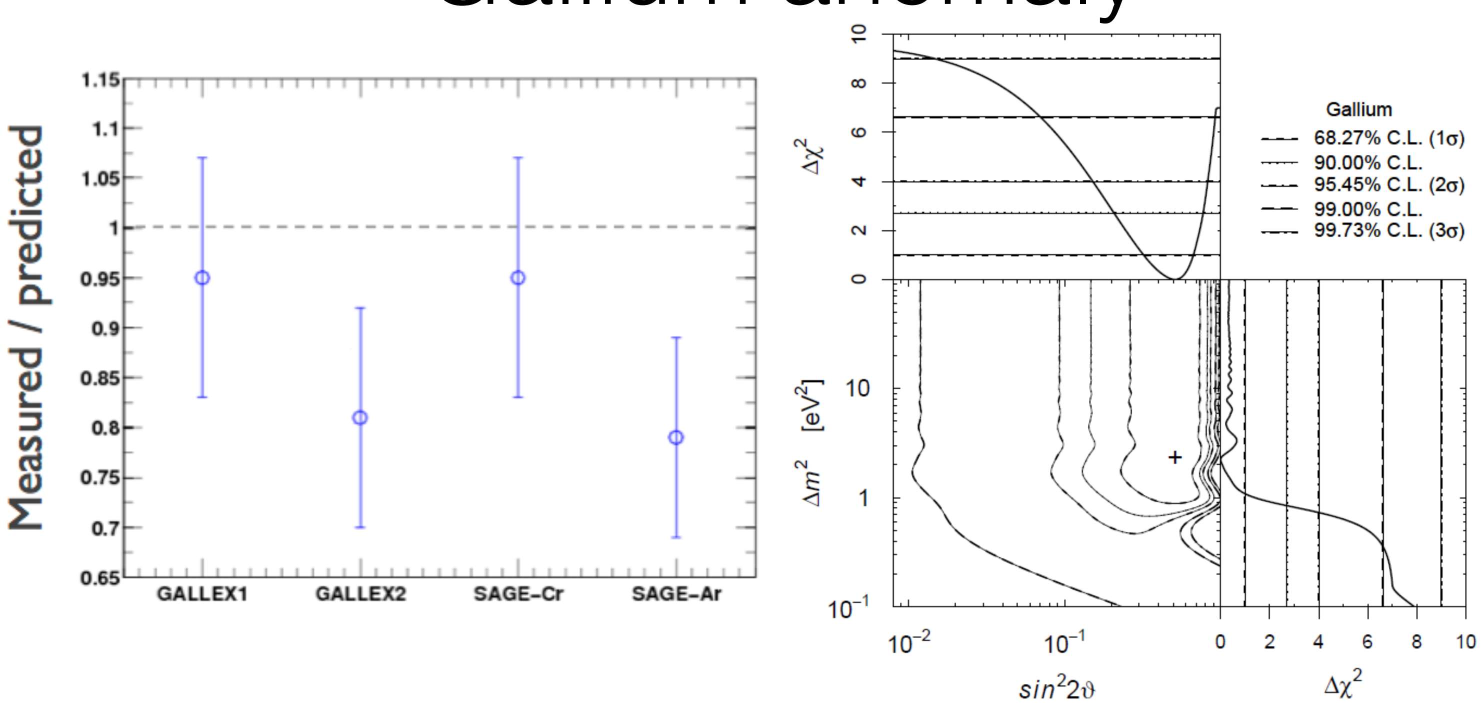
0.025
0.020
0.015
0.010
0.005
0.000
−0.005
0.0
0.5
1.0
1.5
2.0
2.5
MiniBooNE $\overline{\nu}_e$
LSND $\overline{\nu}_e$
MiniBooNE ν_e
ν_e or $\overline{\nu}_e$ 3+2 best fit
ν_e or $\overline{\nu}_e$ 2ν best fit
arXiv:1207.4809
$P(\overline{\nu}_\mu \longrightarrow \overline{\nu}_e)$ or $P(\nu_\mu \longrightarrow \nu_e)$
L/E_ν (meters/MeV)

Signal(?)

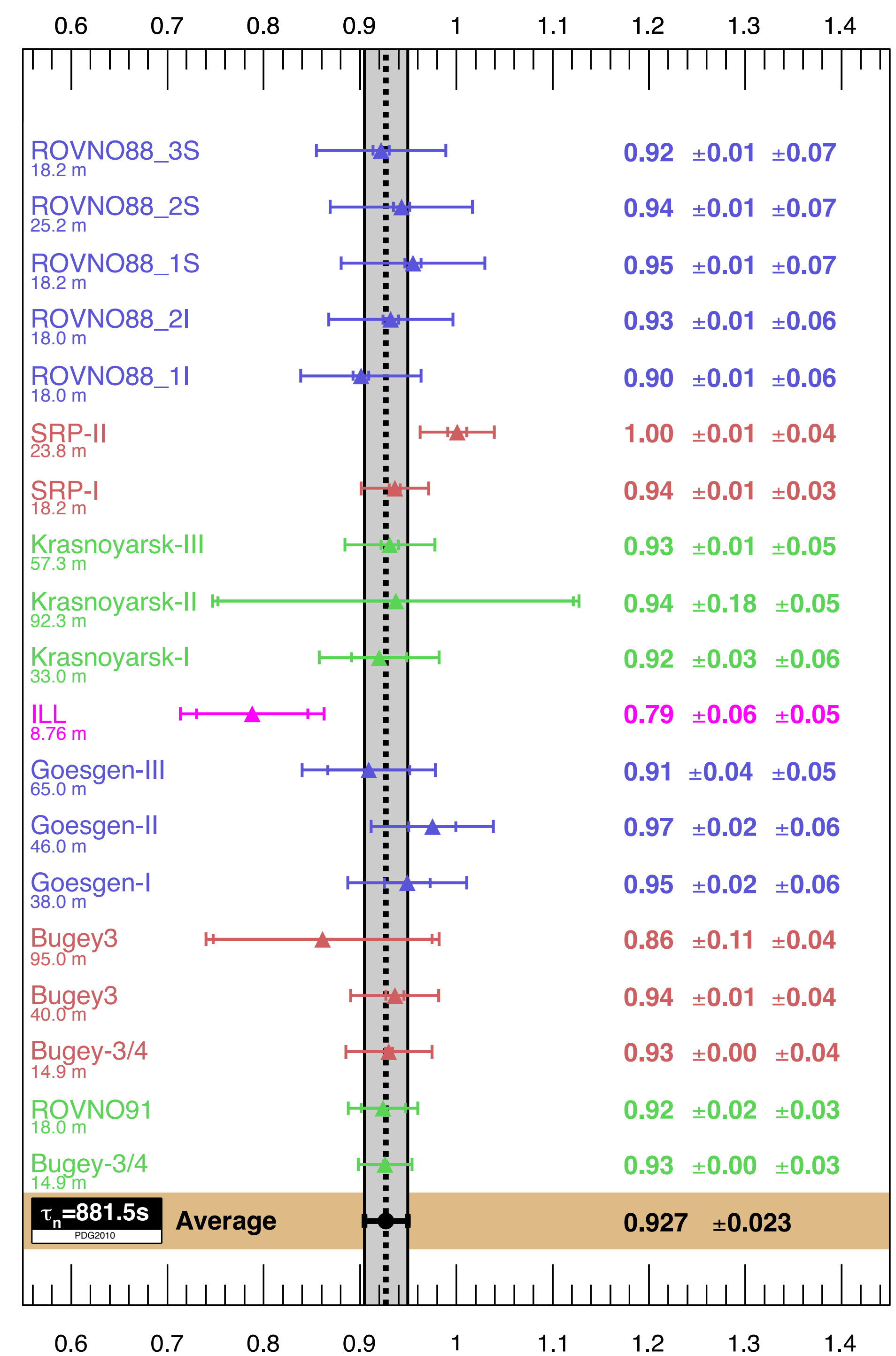
Cosmology



Gallium anomaly

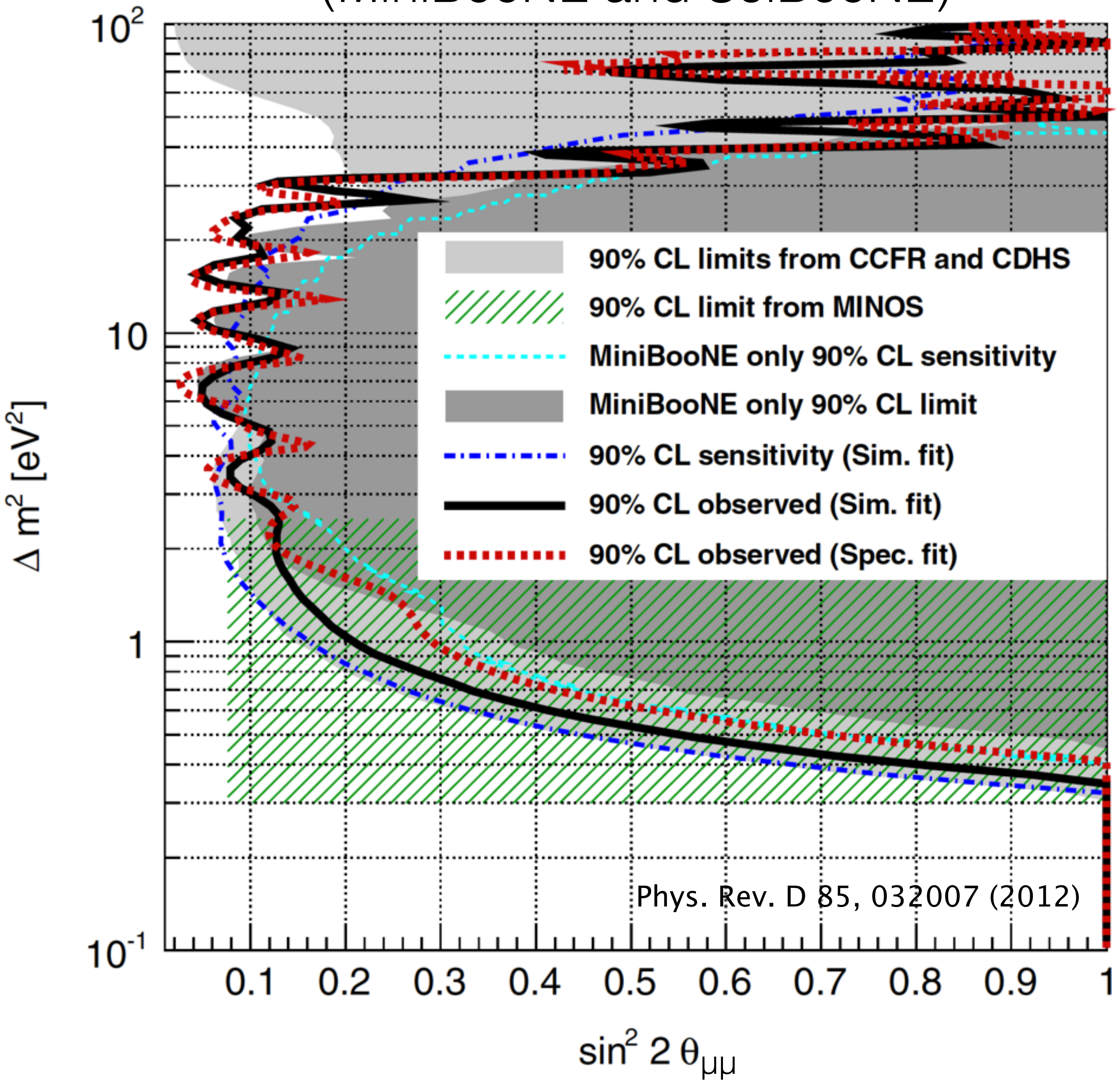


Reactor anomaly



Limits
(let's not forget)

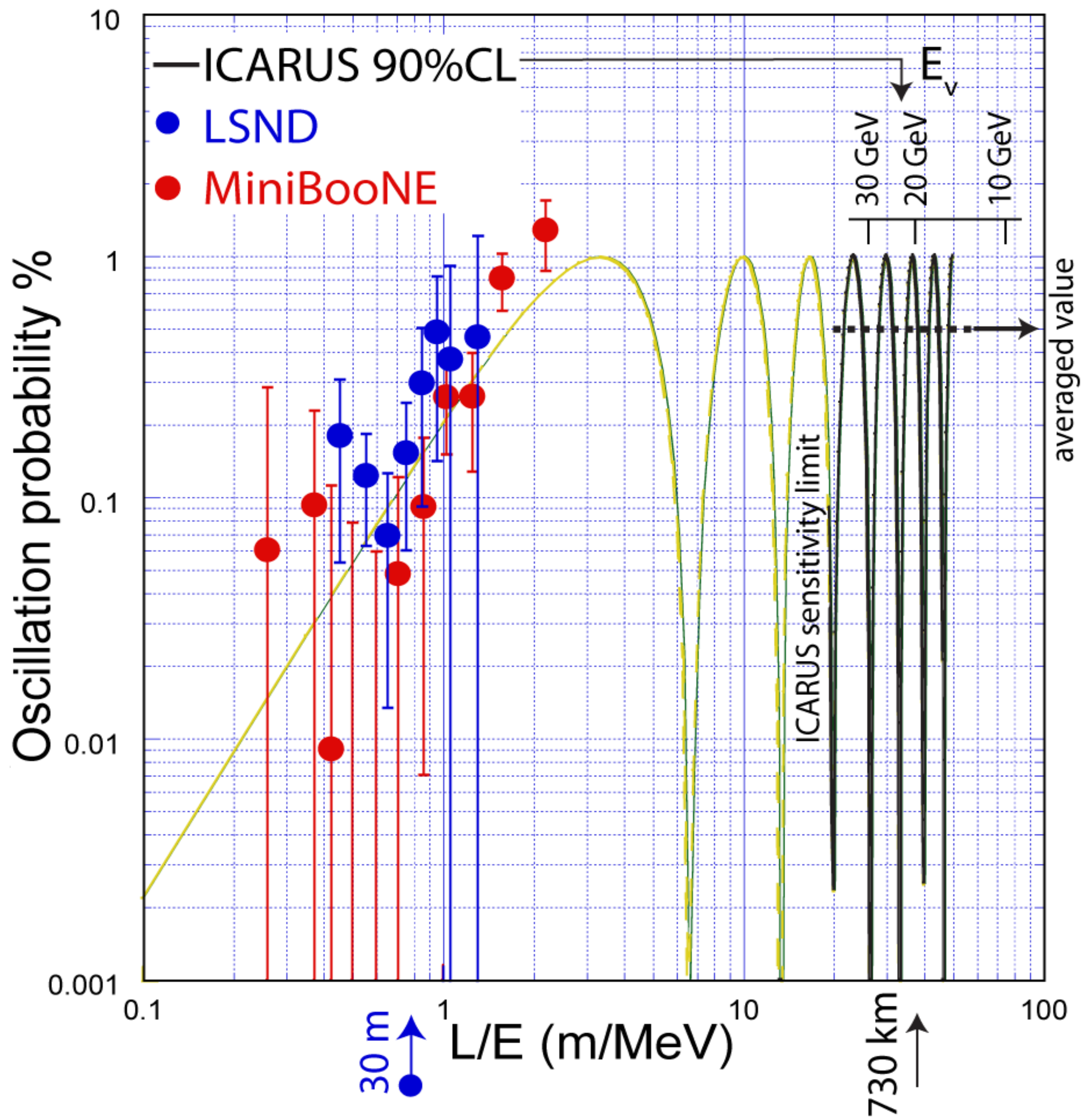
ν_μ disappearance limits
(MiniBooNE and SciBooNE)



- There do exist a number of strict limits on ν_μ/ν_e disappearance and ν_e appearance.
- In particular, the lack of observed muon neutrino/antineutrino disappearance causes issues when trying to form a coherent picture of the sterile neutrino.

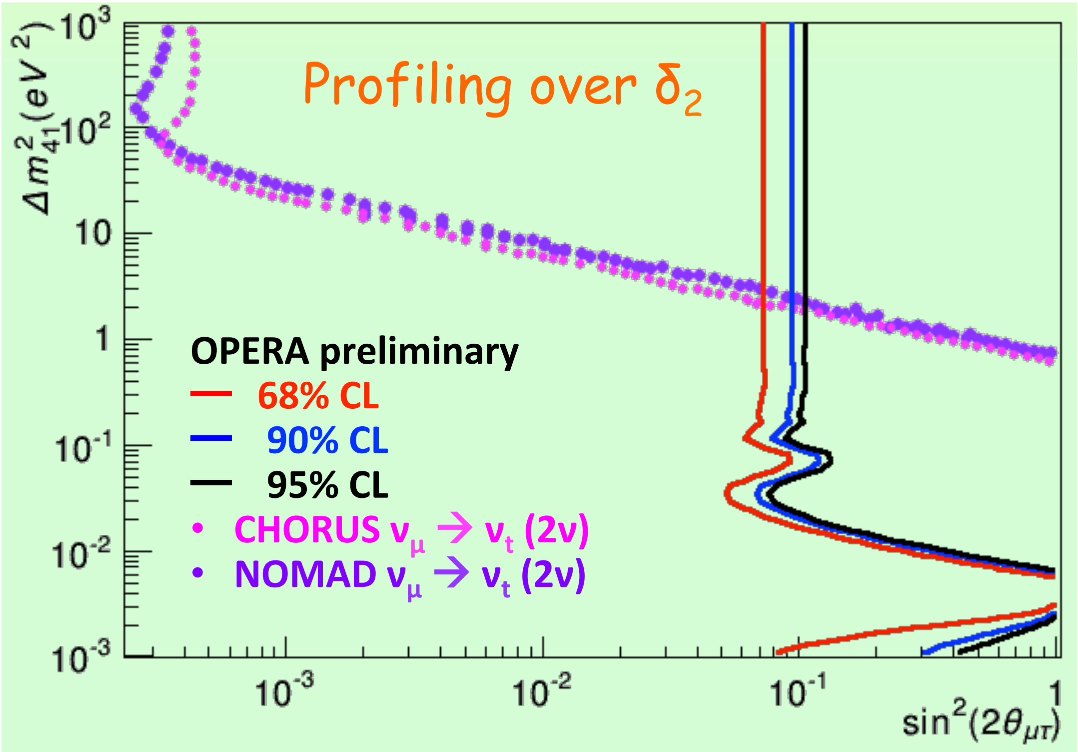
New results!

Electron neutrino appearance
in ICARUS (new limit)

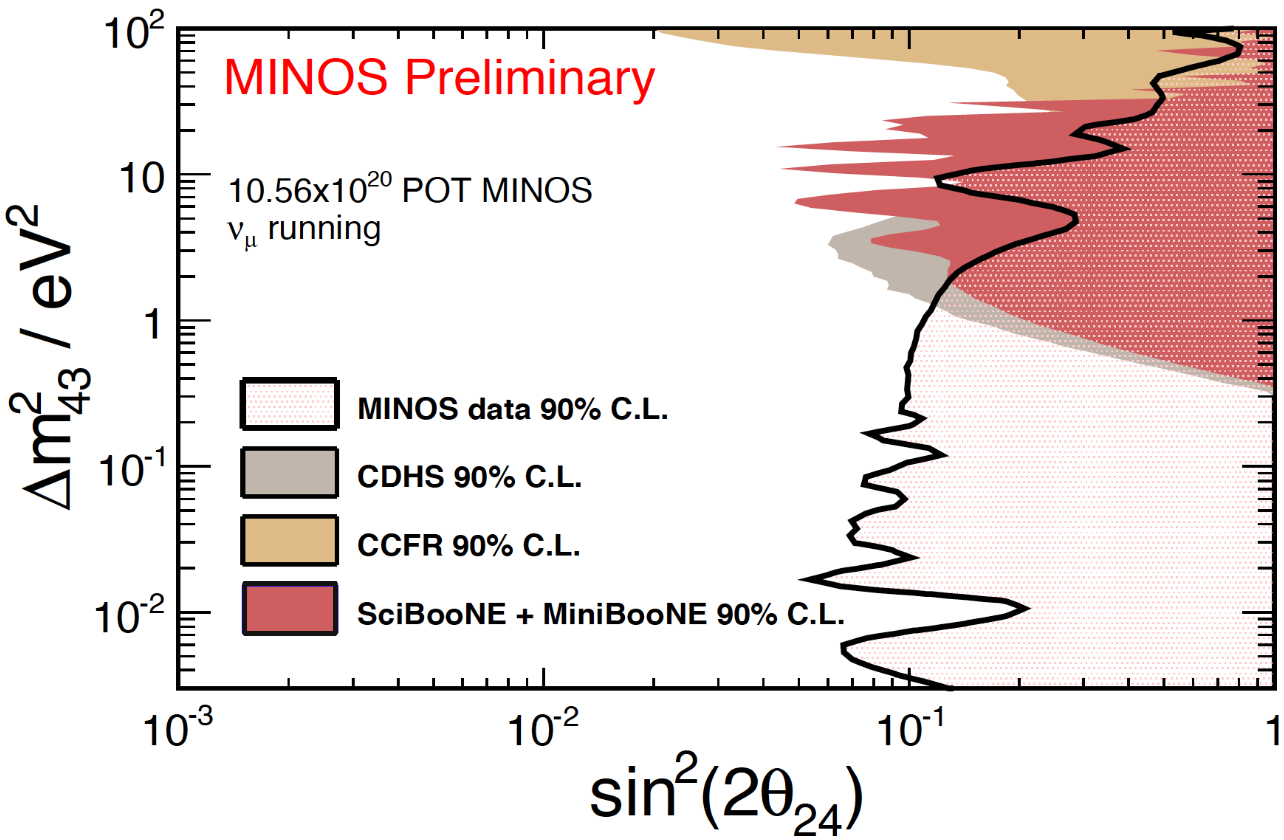


New results!

Tau neutrino appearance (at high Δm²) in OPERA (new limit)



Muon neutrino disappearance in MINOS (new limit)



- I will not cover the future capabilities of MINOS+, OPERA, NOvA, T2K, … as far as sterile neutrino physics goes.
- However, these searches are vital to the sterile program and forming a coherent picture of what's going on! In particular, it is essential that we continue to push in muon disappearance.

(From the “Jaws” movie set;
I don’t think anyone was hurt
as the shark is not real)

Our best efforts to kill
the sterile neutrino

Light sterile neutrino
(or something else
we don’t understand)

Outline

- Where are we with the sterile neutrino?
- Sterile neutrino complications and complaints.
- What do we need to do to solve the light sterile neutrino issue?
- An overview of the future accelerator-based experiments in the field.

Complications

- How many light sterile neutrinos are there? 0, 1, 2, 3?
- Is there a difference between neutrino and antineutrinos?
- If it is physics, could there be other sources of the anomalies?
- **I will largely ignore these complications.** When talking about sterile neutrino sensitivity it's easiest to just assume 3+1. This doesn't tell the whole story but it puts everyone on the same page.

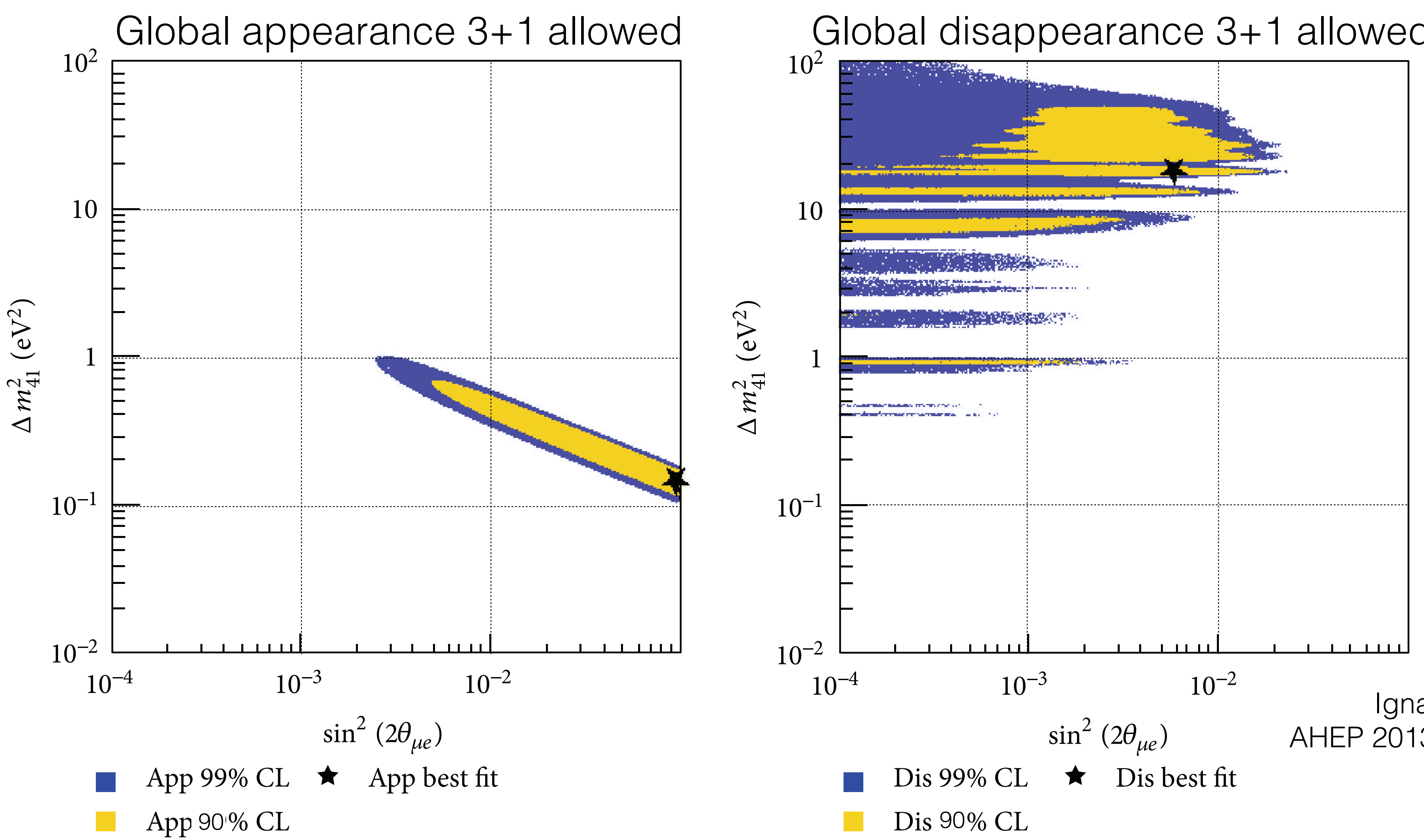
3+1 assumptions

3+1 appearance $$P(\nu_\alpha \to \nu_{\beta\neq\alpha}) = 4|U_{\alpha 4}|^2|U_{\beta 4}|^2 \sin^2(1.27\Delta m^2_{41} L/E)$$

3+1 disappearance $$P(\nu_\alpha \to \nu_{\not\alpha}) = 4|U_{\alpha 4}|^2(1-|U_{\alpha 4}|^2) \sin^2(1.27\Delta m^2_{41} L/E)$$

Warning: the complications may actually be quite important

- There is tension between appearance and disappearance measurements.



Ignarra, *et al.*
AHEP 2013 163897 (2013)

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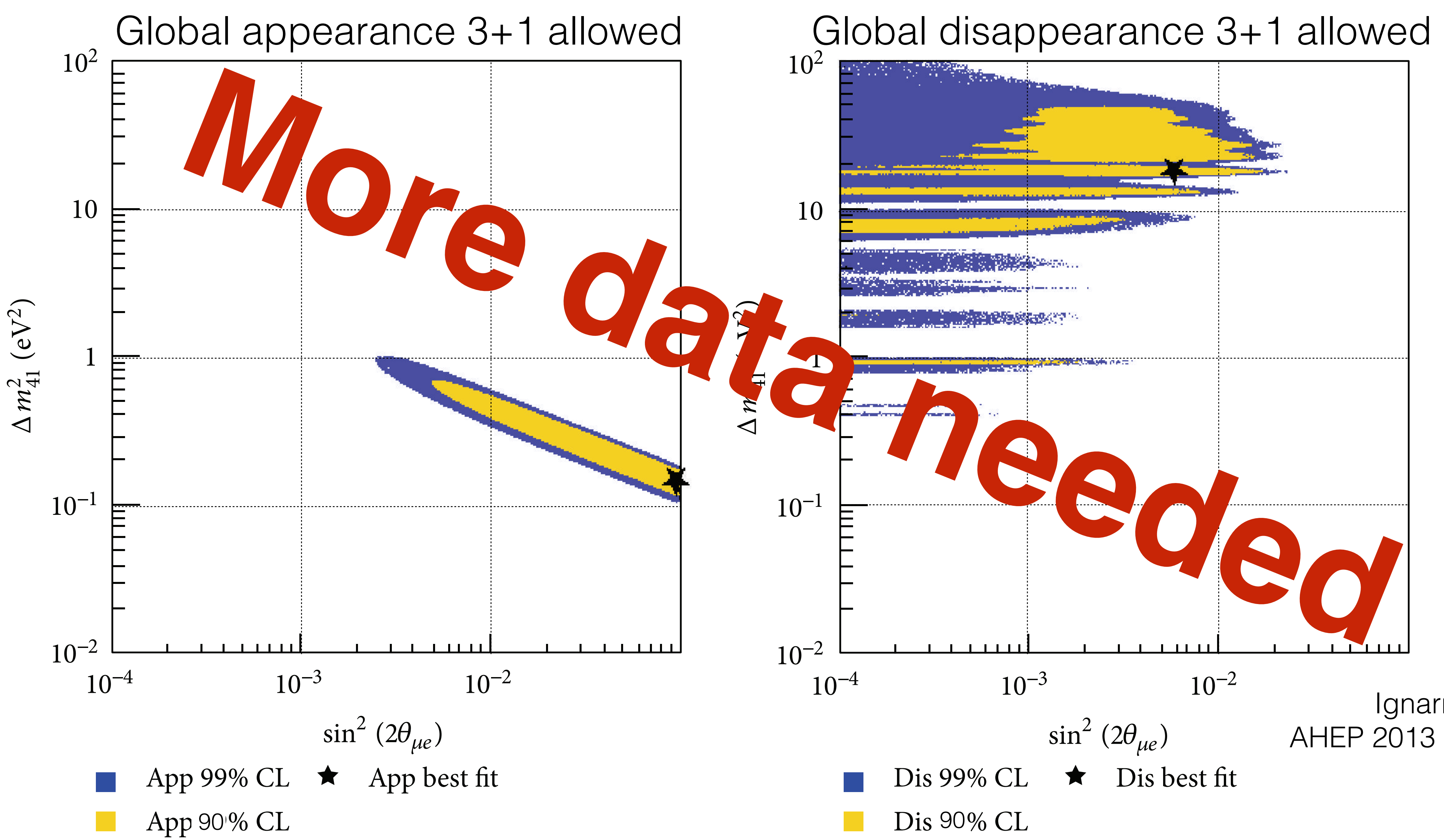
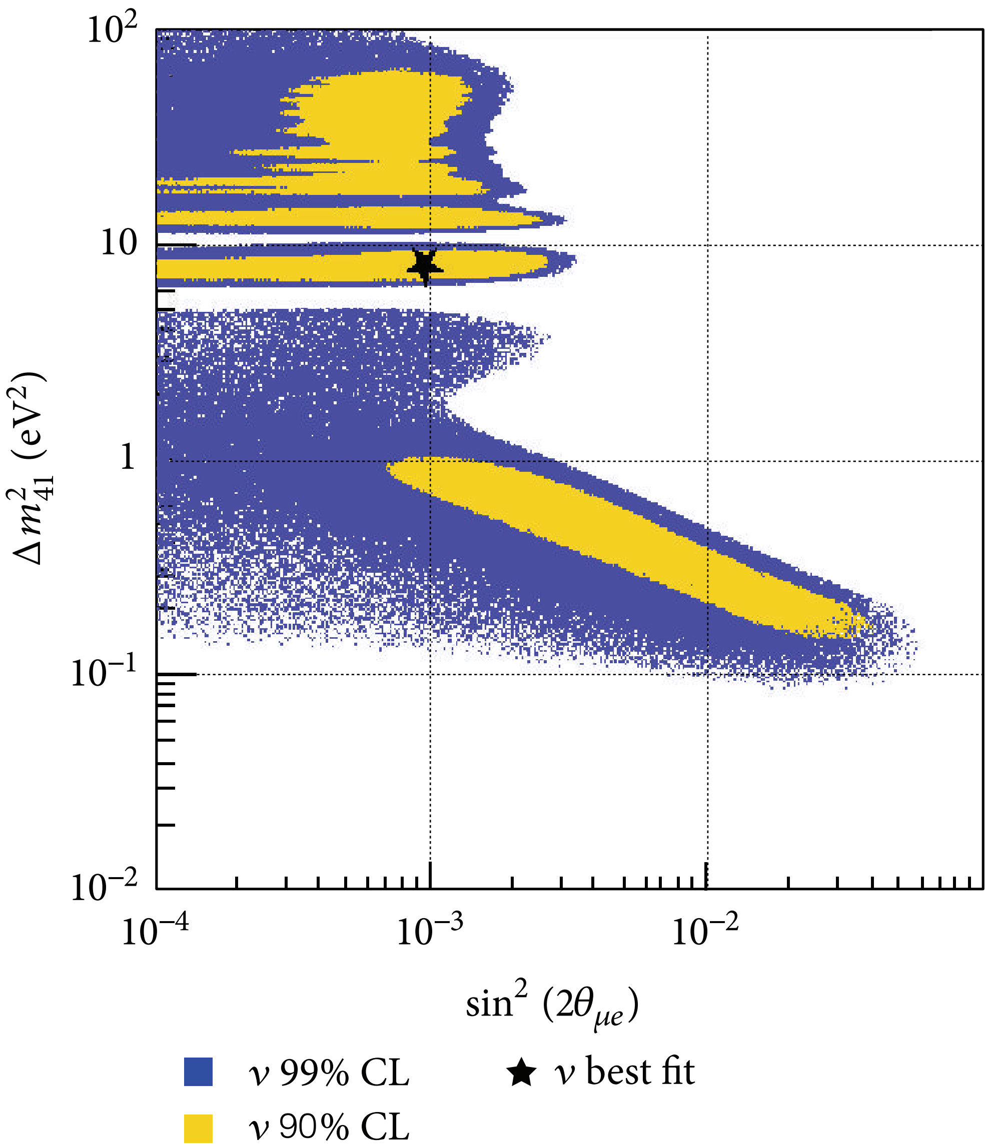


Ignarra, *et al.*
AHEP 2013 163897 (2013)

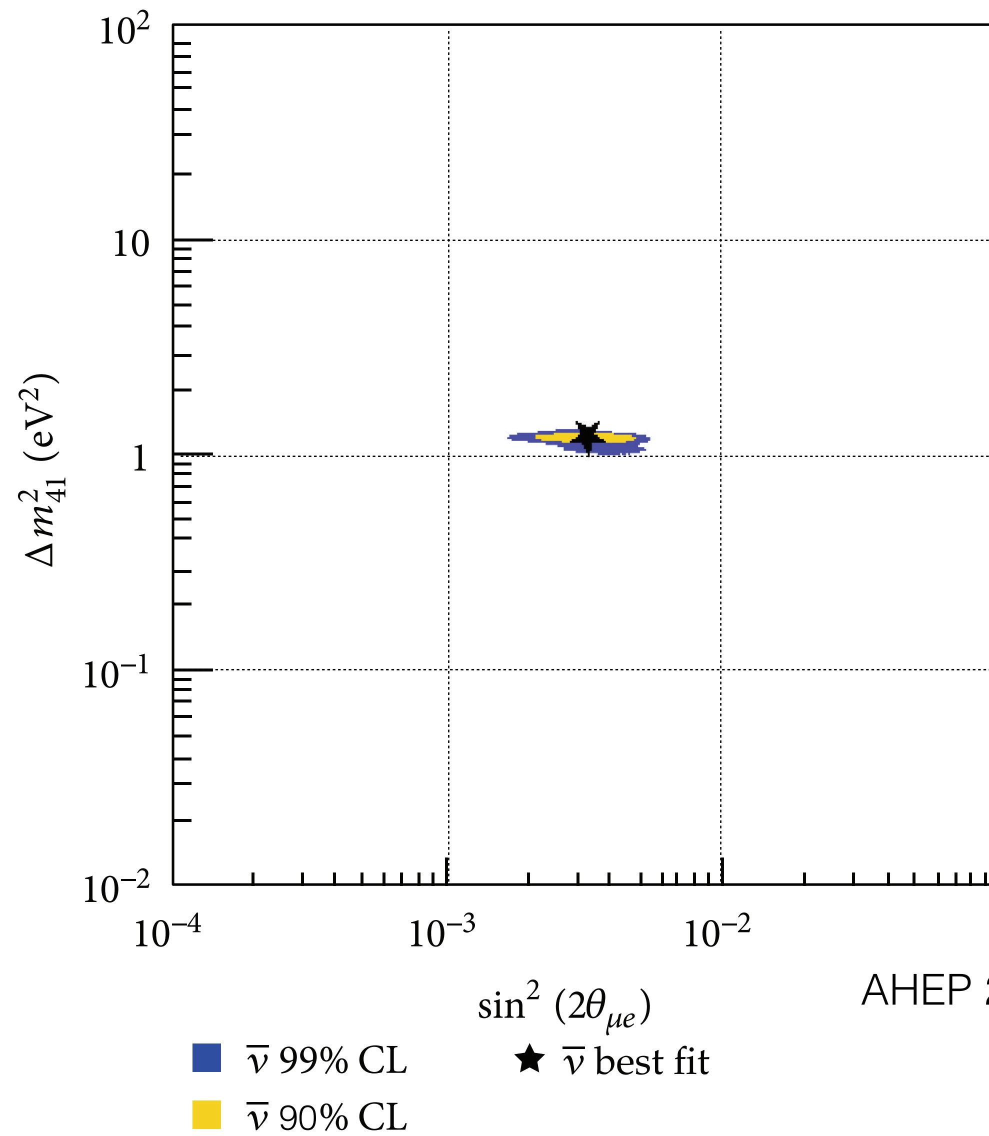
Warning: the complications may actually be quite important

- There is tension between neutrino and antineutrino measurements.

Global neutrino 3+1 allowed



Global antineutrino 3+1 allowed



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AHEP 2013 163897 (2013)

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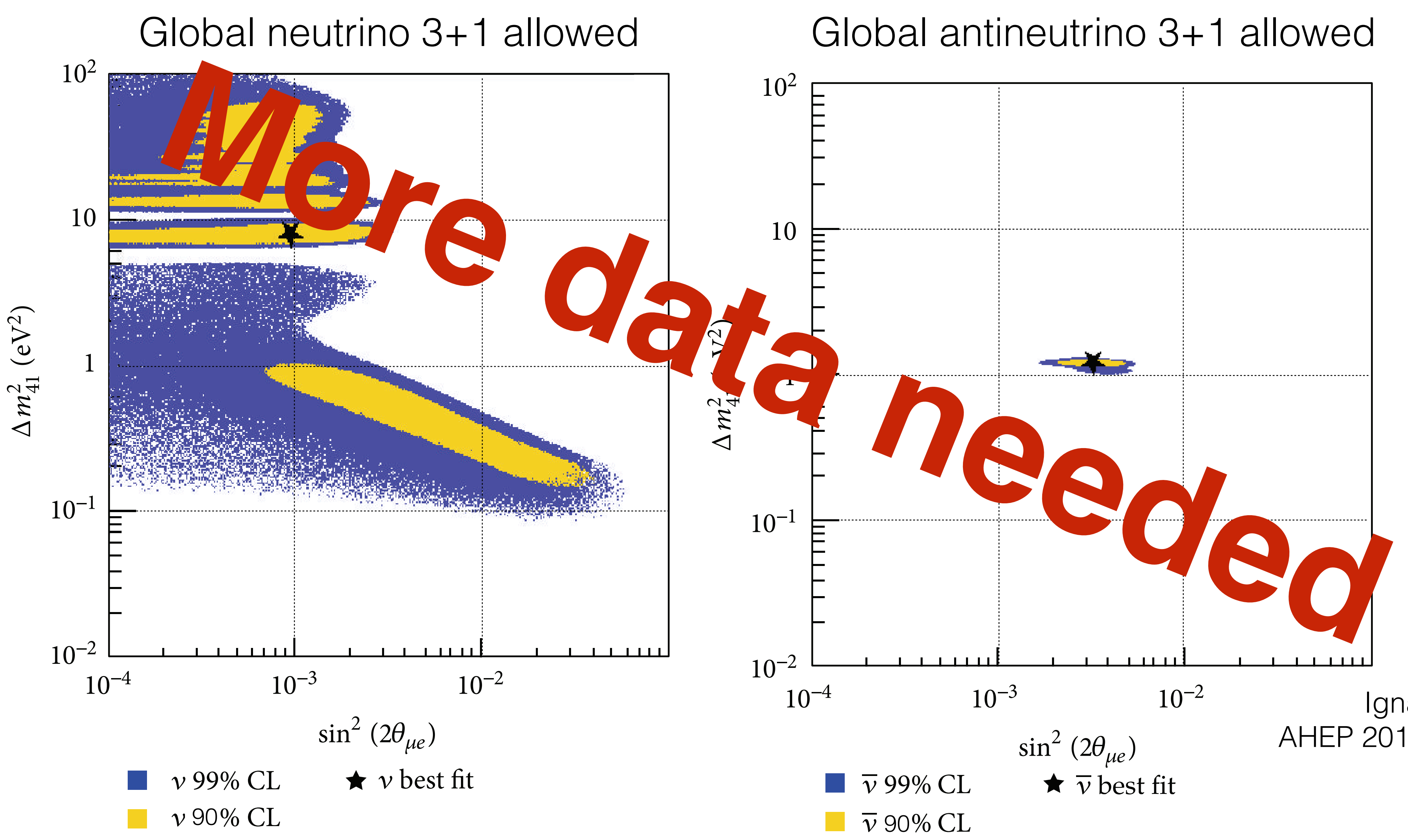


Ignarra, *et al.*
AHEP 2013 163897 (2013)

A 3+1 model

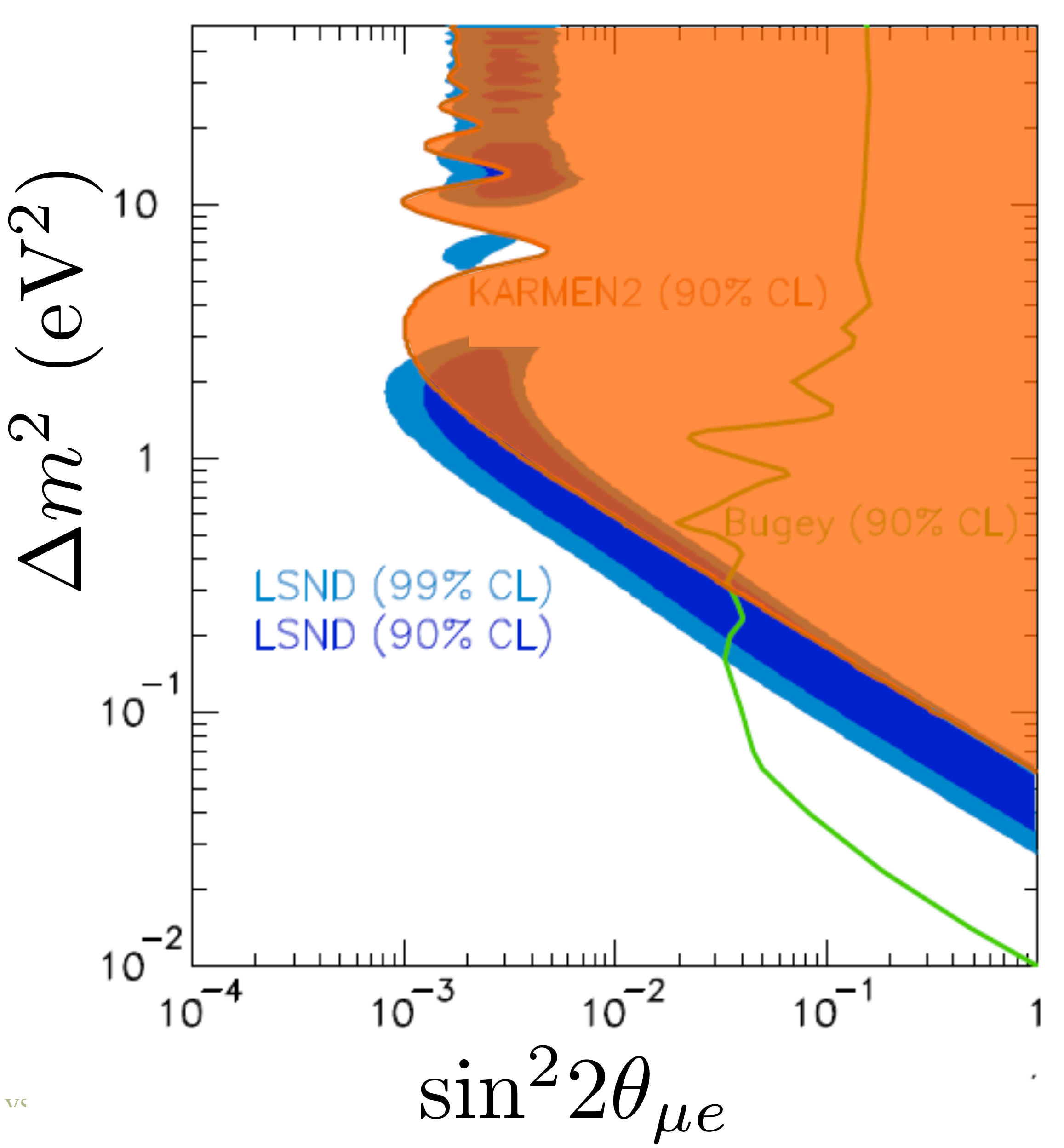
A CP-violating 3+3 model with Lorentz violation

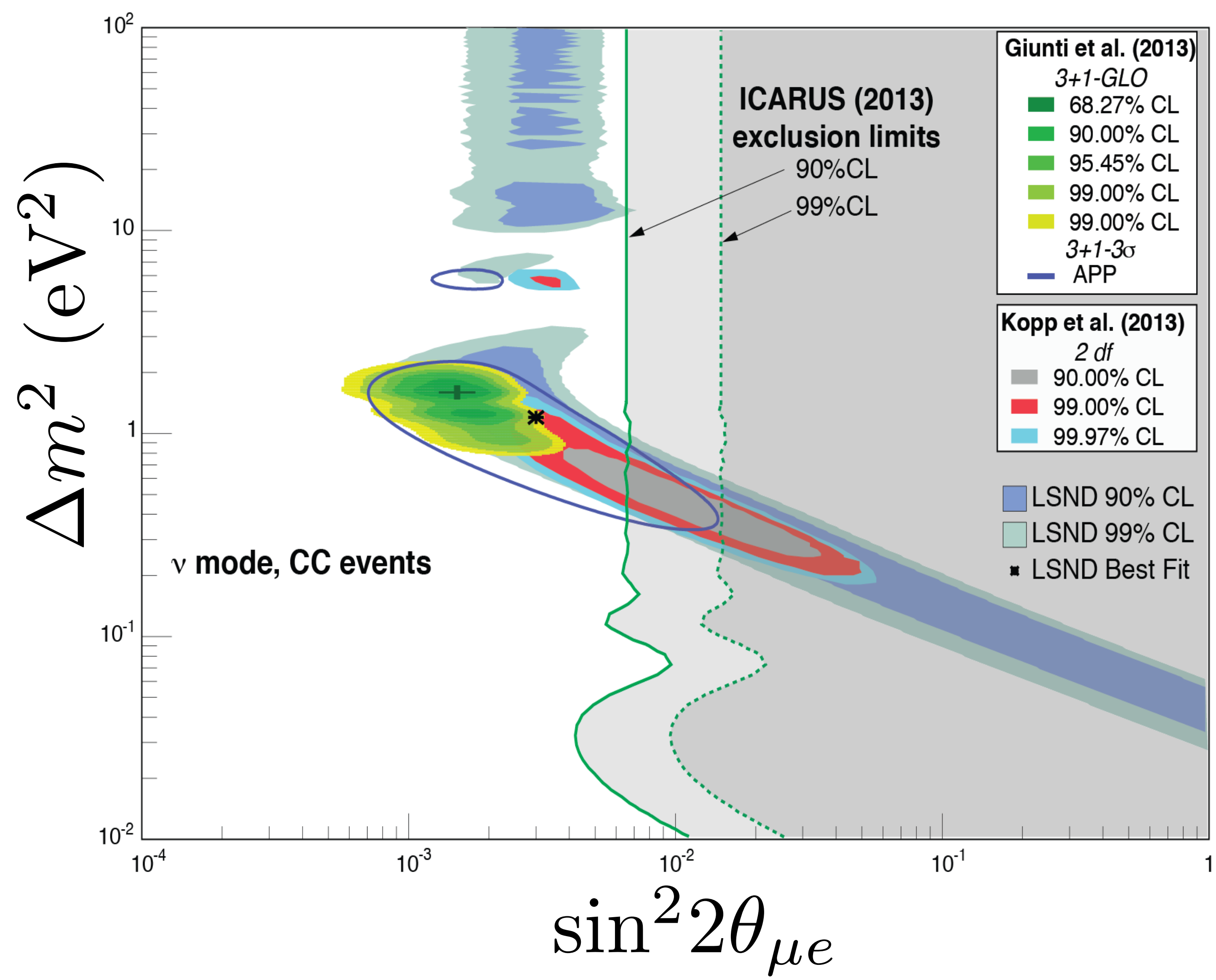
Sterile neutrino complaints

- “We don’t even know what we’re looking for”.
  - I agree. But, if we want to figure out what (if anything) is going on, we need to probe the parameter space.
  - Parameter space can be defined here as: **(Δm^2, $\sin^2 2\theta$)** and/or **(L, E_ν)** and/or **(E_ν)**.
  - All spaces are interesting and, even in the absence of a sterile neutrino, can teach us about accelerator-produced neutrinos for the future of the field!

Probing the parameter space, in (Δm^2, $\sin^2 2\theta$)

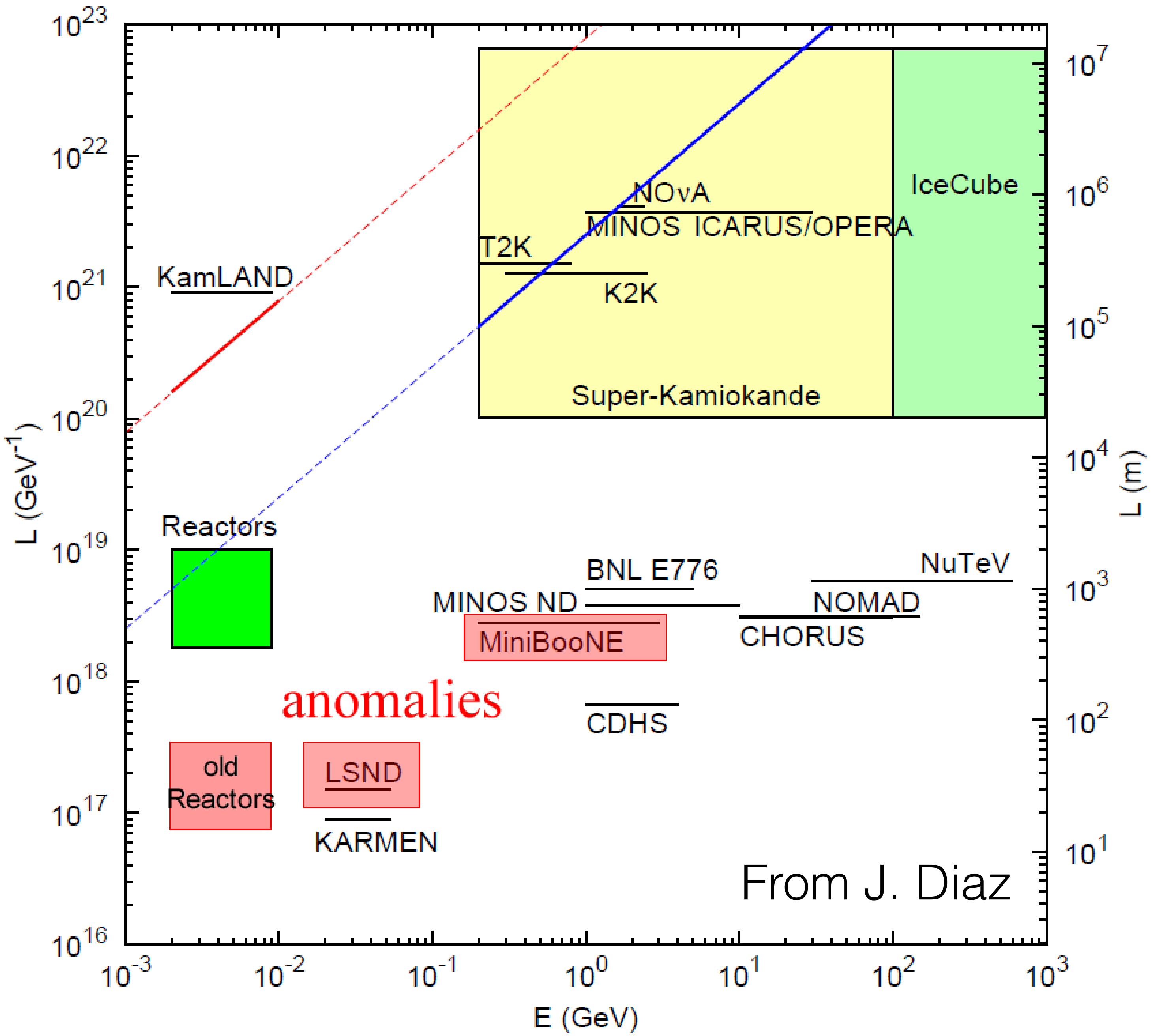
(hypothesis: anomalies may be due to one or more sterile neutrinos)





Probing the parameter space, in (L,E$_\nu$)

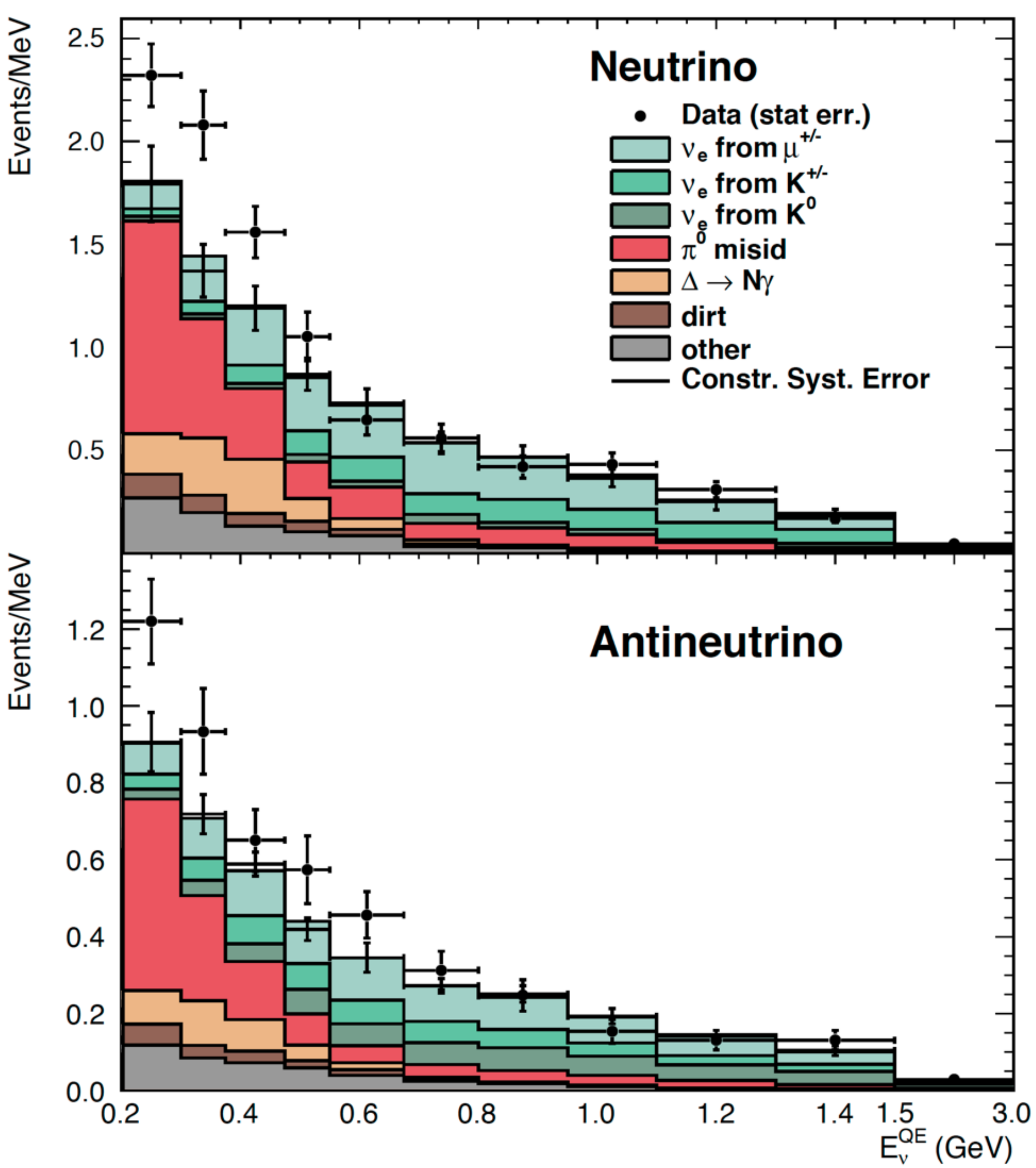
(hypothesis: anomalies may be due to Lorentz violation or something else exotic)



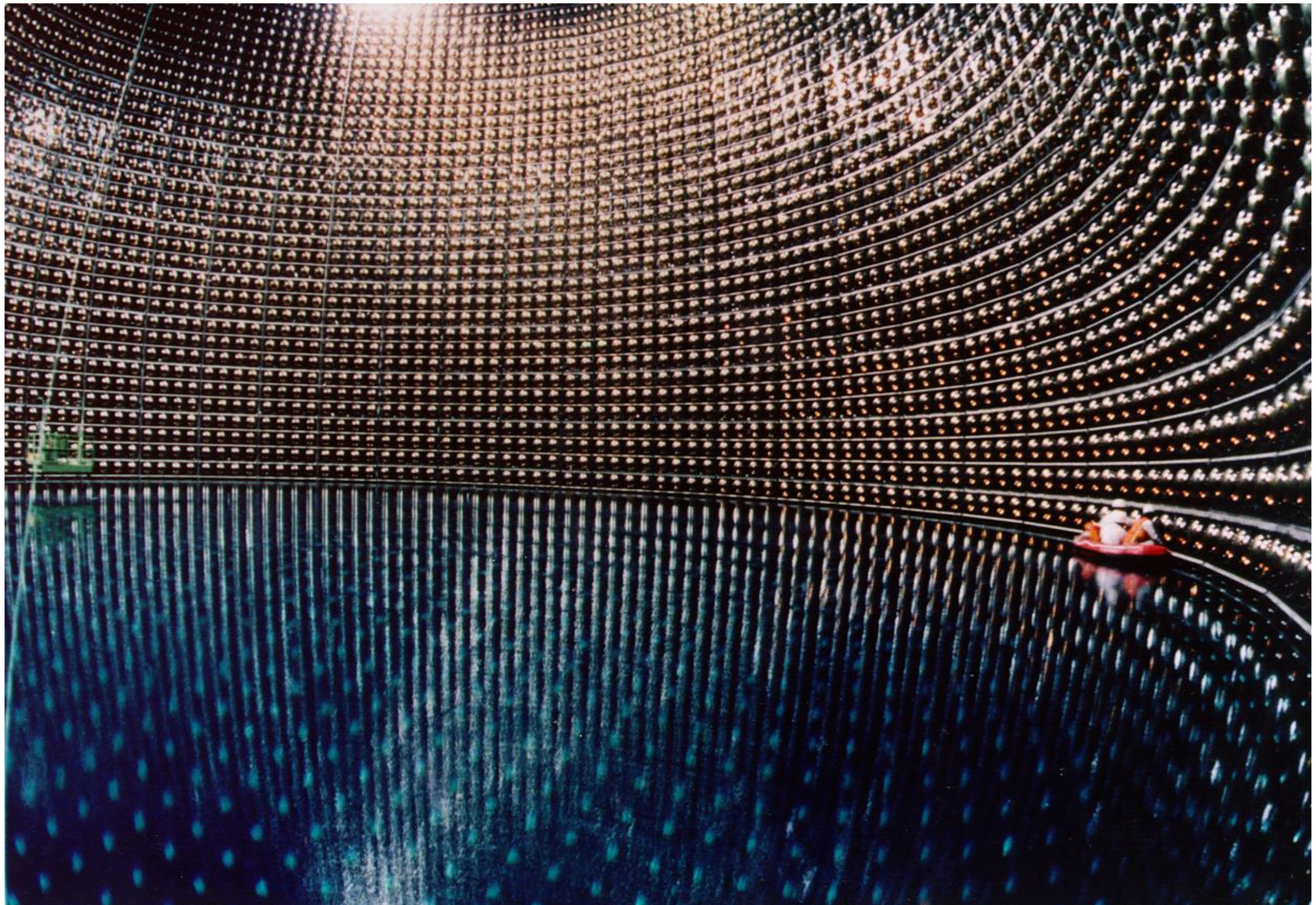
- Non-L/E oscillation behavior (mixing due to more than just mass) is expected in a number of exotic scenarios.
- Maybe we have just 3 neutrinos and some other profound physics is taking place!

Probing the parameter space, in (E_ν)

(hypothesis: anomalies may be due to lack of neutrino interaction understanding, an underestimated background, energy reconstruction issues, or some other systematic)

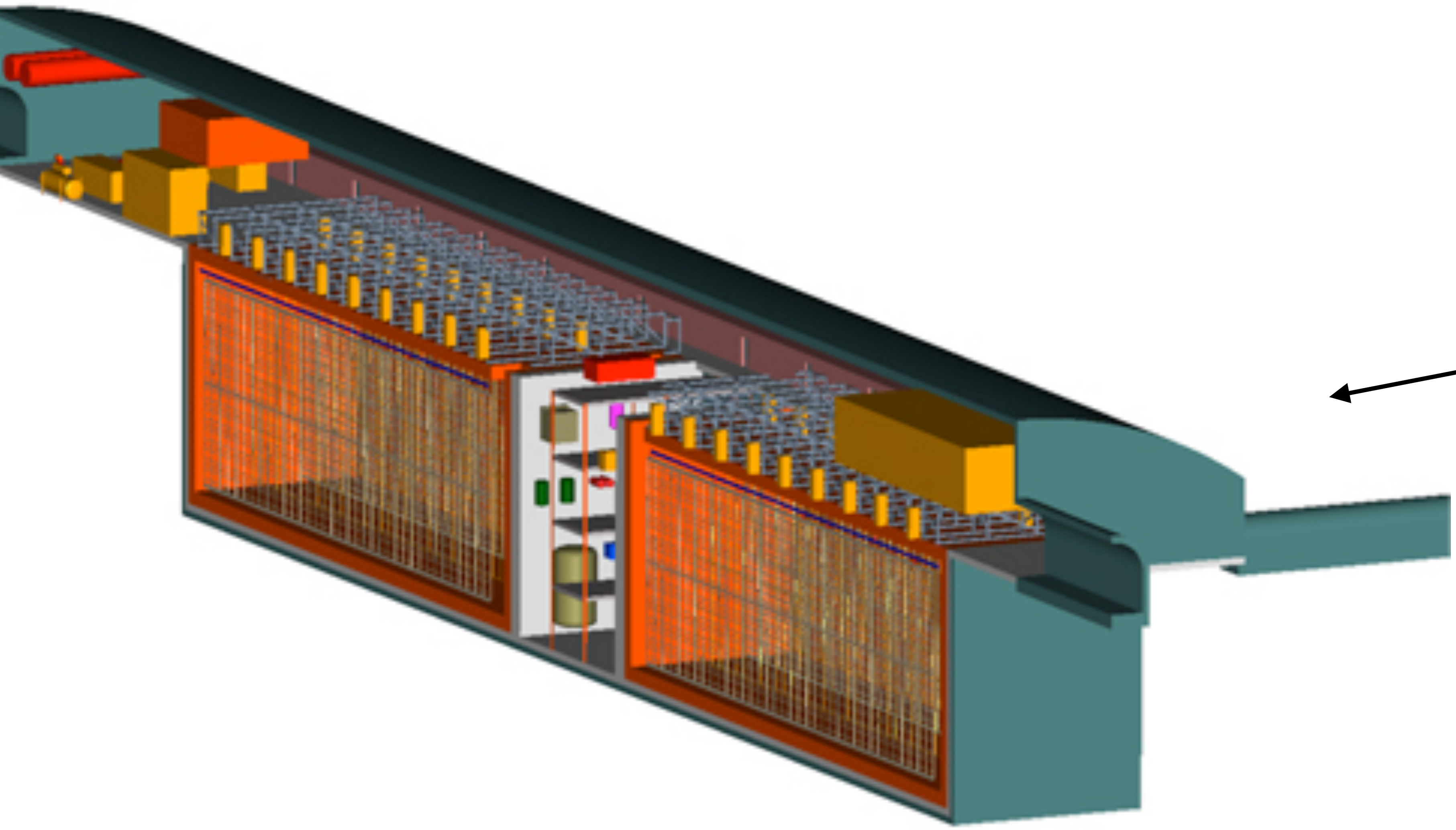


This hypothesis and its resolution may be important for our long baseline friends, especially those at low energy (see: Hyper-K, ESSνSB, LBNE second and third oscillation maxima).



The future of the accelerator-based program

Light sterile neutrino (or something else we don't understand)



The future of the accelerator-based program

(a “super shark”, capable of living in 87 K)

Light sterile neutrino (or something else we don’t understand)

Short baseline complaints

- “The non-oscillation physics is not compelling by itself”.

This is simply incorrect. But, don’t take my word for it.

Topic	Cites as of 5/30/2014
CCQE 1	188
Coherent pi0	97
CCpi+/CCQE ratio	58
NCpi0	68
CCQE 2	204
NC elastic 1	77
CCpi0	79
CCpi+	68
CCQE 3	45
NC elastic 2	6
Total	890

MiniBooNE xsec analyses

Short baseline complaints

- “We can just do the cross section and interaction physics with our near detector in the long baseline program”.

Developing theory, phenomenology, and simulation takes time and people.

There is nothing like **data** to spur this along.

We need to be considering the issues associated with the neutrino interaction now!

Outline

- Where are we with the sterile neutrino?
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- An overview of the future accelerator-based experiments in the field.

Defining “definitive”

Did MiniBooNE definitively solve the sterile neutrino issue?

No.

Defining “definitive”

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No.

The problem is that they saw something.

The answer might be a ‘yes’ if they didn’t see anything.

(in our field, it is easier to refute than to confirm)

Defining “definitive”

Did MiniBooNE definitively solve the sterile neutrino issue?

No.

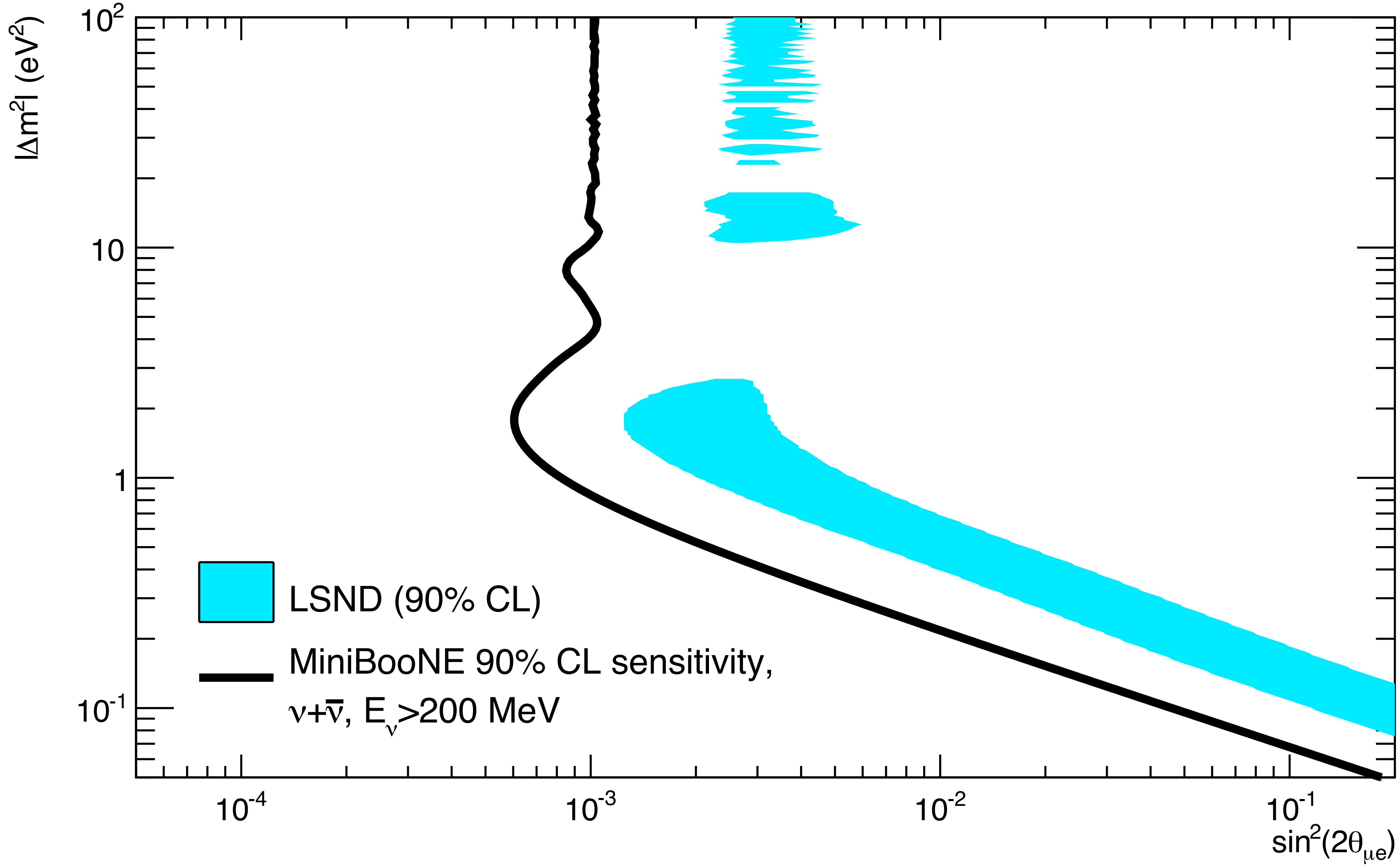
The problem is that they saw something.
The answer might be a ‘yes’ if they didn’t see anything.
(in our field, it is easier to refute than to confirm)

Therefore, a future “definitive” test requires that the achievable sensitivity *significantly* surpasses MiniBooNE’s sensitivity, under a 3+1 hypothesis.

We want to be able to definitively refute
AND be able to definitively confirm.

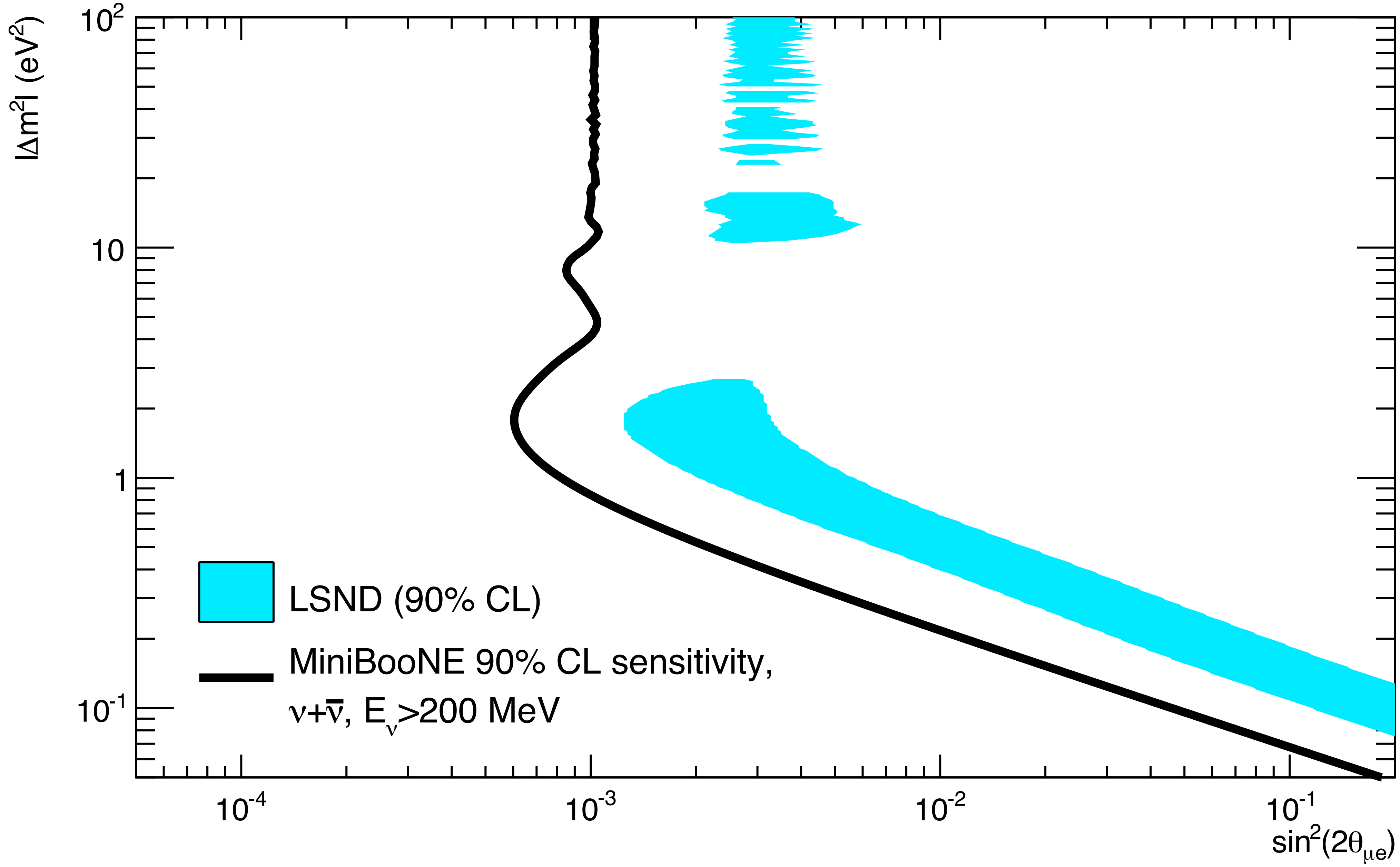
What was MiniBooNE's sensitivity*?

*The *actual* experimental sensitivity achieved (not from the proposal)



From MiniBooNE data release:
http://www-boone.fnal.gov/for_physicists/data_release/nue_nuebar_2012/

This sensitivity is not good enough to be definitive!!



From MiniBooNE data release:
http://www-boone.fnal.gov/for_physicists/data_release/nue_nuebar_2012/

A definitive resolution

- Does the experiment have a good chance to see an unambiguous wiggle in L/E?
- Does the experiment have a sensitivity which significantly surpasses MiniBooNE's?
- Does the experiment have a good chance to see an oscillation signal in multiple channels and/or with neutrinos and antineutrinos?

I require at least 2 out of 3 to be "definitive".

Your mileage may vary.

Outline

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Where are we going?

- We are definitely moving into the “LAr detector(s) at FNAL’s Booster Neutrino Beamline” phase of the global accelerator-based sterile neutrino search program.
- There are a number of other accelerator-based sterile neutrino ideas as well:
  - LSND-style decay-at-rest w/ liquid scintillator.
    - OscSNS, JPARC-MLF
  - Non-LAr-R&D sterile searches with technology relevant for the future.
    - nuSTORM, IsoDAR

I am going to show some sensitivity predictions for various experiments.

Please be careful when considering these.

Be careful when considering sensitivity estimates!

- Systematics vs. statistics limited.
- Where are the detector and background assumptions coming from?
- What are the largest sources of systematics?
- Is the technology proven? How is “proven” defined?
- Reliance on simulation.
- Near detector?
- Rate-only vs. energy-shape-only vs. rate+shape.
- Are correlations between near and far detectors taken into account?

MicroBooNE

- Along with vital neutrino cross section measurements and LArTPC R&D, MicroBooNE will definitively address the MiniBooNE low-E excess.

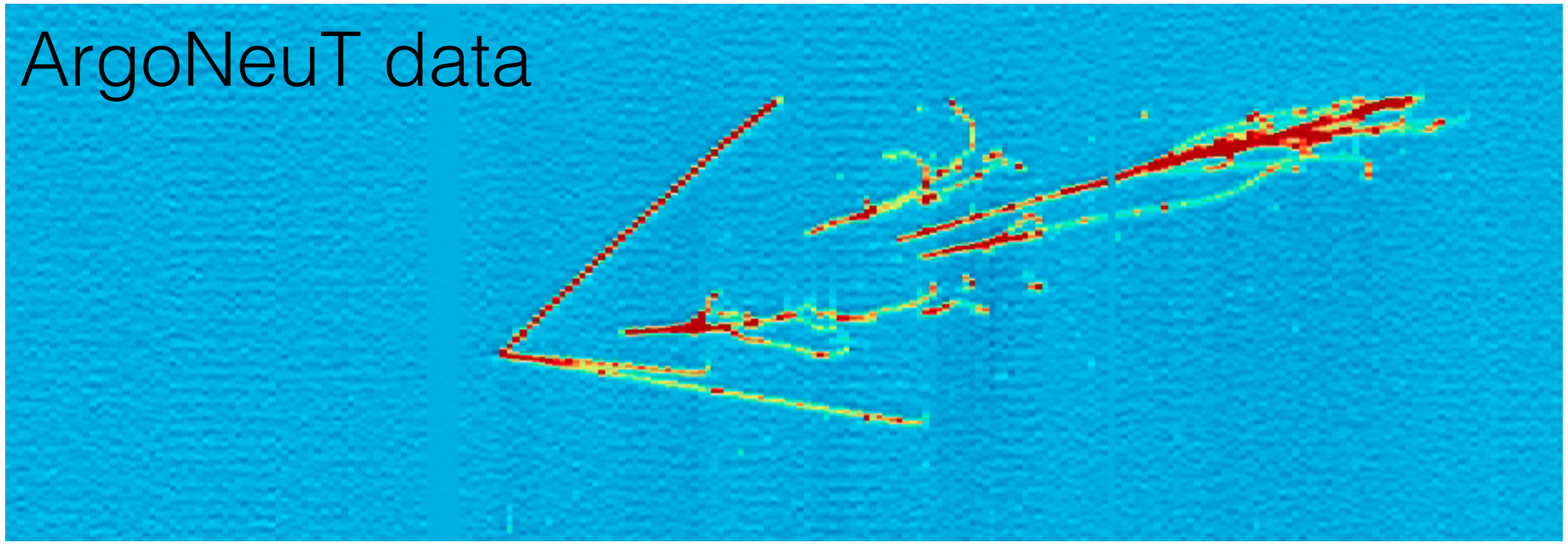
- Unfortunately, MicroBooNE suffers from a very specific issue when it comes to being able to definitively address the sterile neutrino: It's not big enough.

- MicroBooNE represents the first step in a phased LAr-based program at FNAL to address the sterile neutrino definitively and will be providing excellent physics in the very near future.

	Primary Channel	Other osc channels	Definitive sterile?	Other physics	Tech R&D?	Cost	Why worry?	Comment
MicroBooNE (π DIF)	$\nu_\mu \rightarrow \nu_e$	$\nu_\mu \rightarrow \nu_\mu$	—	GeV-scale xsec	Yes	$20M	tech, cosmics	Exists!

The future of LAr at FNAL

- Two new proposals went before the January 2014 PAC at FNAL to take advantage of the Booster Neutrino Beamline in addressing the sterile neutrino.
  - 1. The LAr1-ND phased approach, which calls for a near detector in the existing SciBooNE hall at 100m, while looking toward a future large far detector.
  - 2. The ICARUS approach, taking advantage of the existing T600 detector as a far detector and combining with a near detector.
- Since the January PAC, members of both LAr1-ND and ICARUS have been working together with the lab to further develop these plans.



The *proposed* future of the LAr program
at FNAL is rapidly evolving (and coming into focus).

LAr1-ND MicroBooNE ICARUS (T150+T600)

Combining forces!

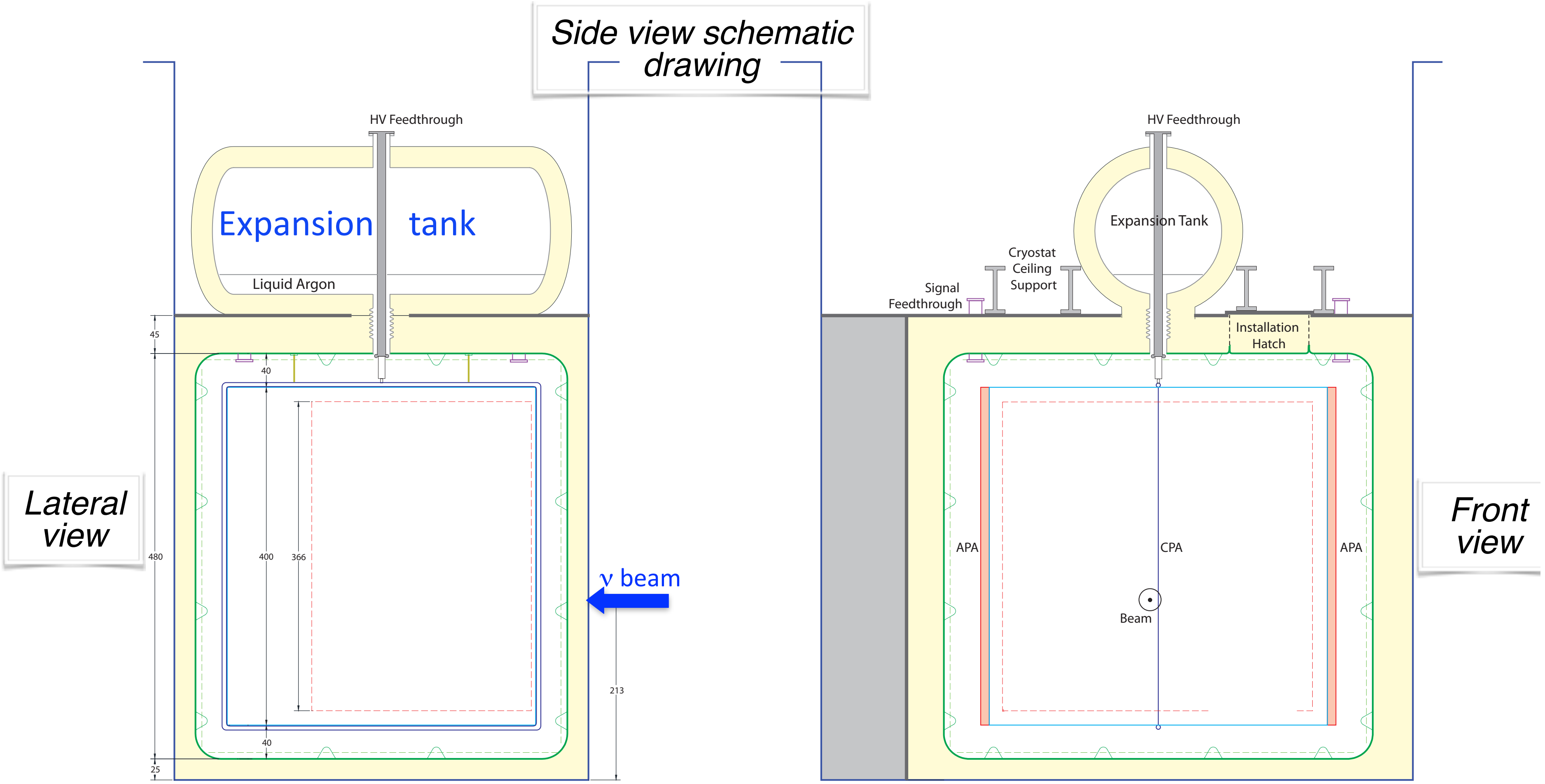
A coherent, collaborative, international program at FNAL's BNB (and NuMI off-axis) likely featuring three detectors by 2018: near, MicroBooNE at mid-distance, and far.

(a CDR is to be presented at the FNAL July 2014 PAC)

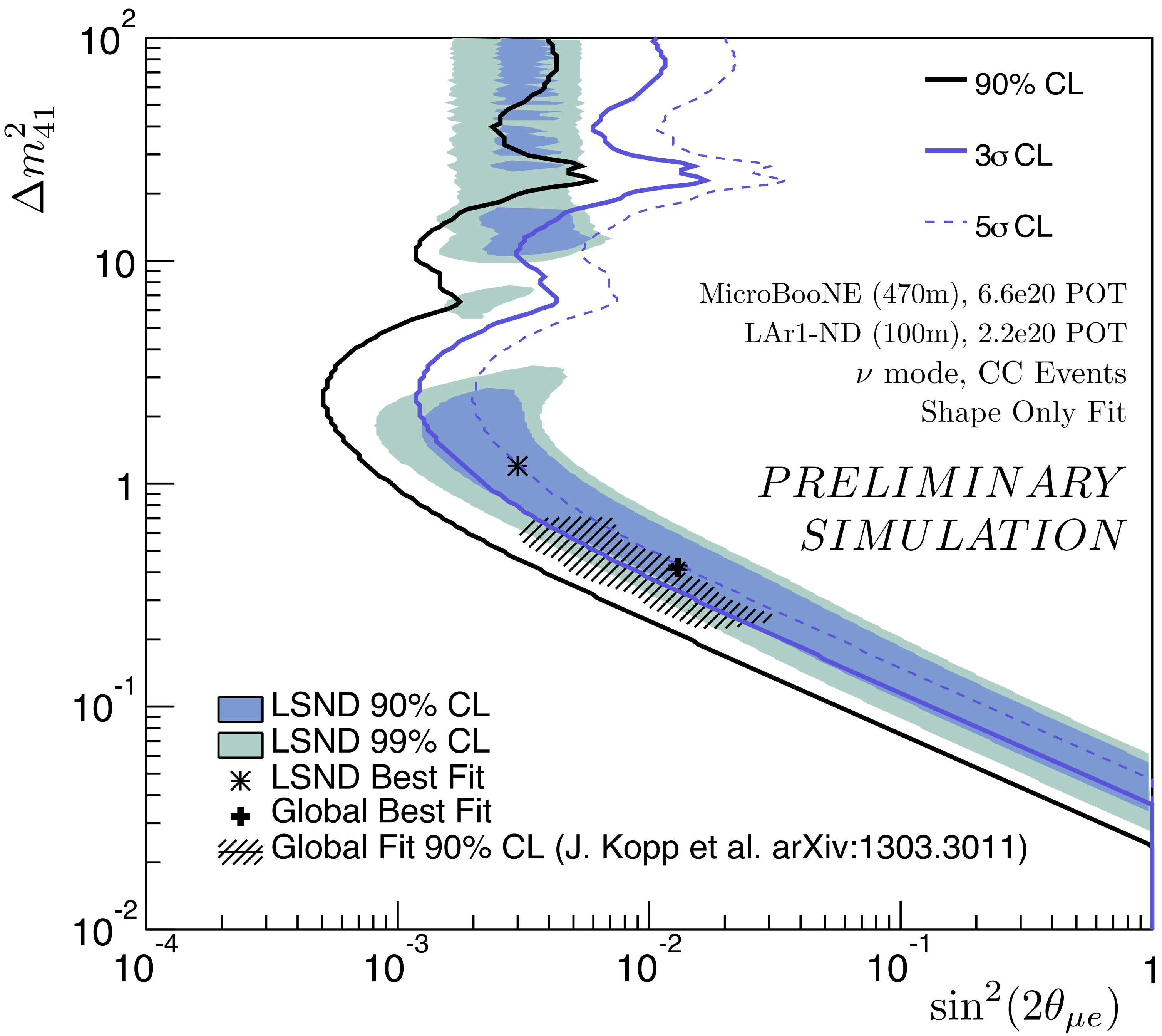
LAr1-ND

- A proposed 82 ton LArTPC near detector at 100 m in FNAL's BNB.
- Can provide a "near sampling" of the beam and help interpret any observed excess. Answers the question: Is excess intrinsic to beam or not?

The "SciBooNE Hall" at 100 m



LAr1-ND + MicroBooNE sensitivity



This is "shape-only" and can be considered conservative.

Shape-only means that the prediction for the far detector rate in energy comes from the near detector.

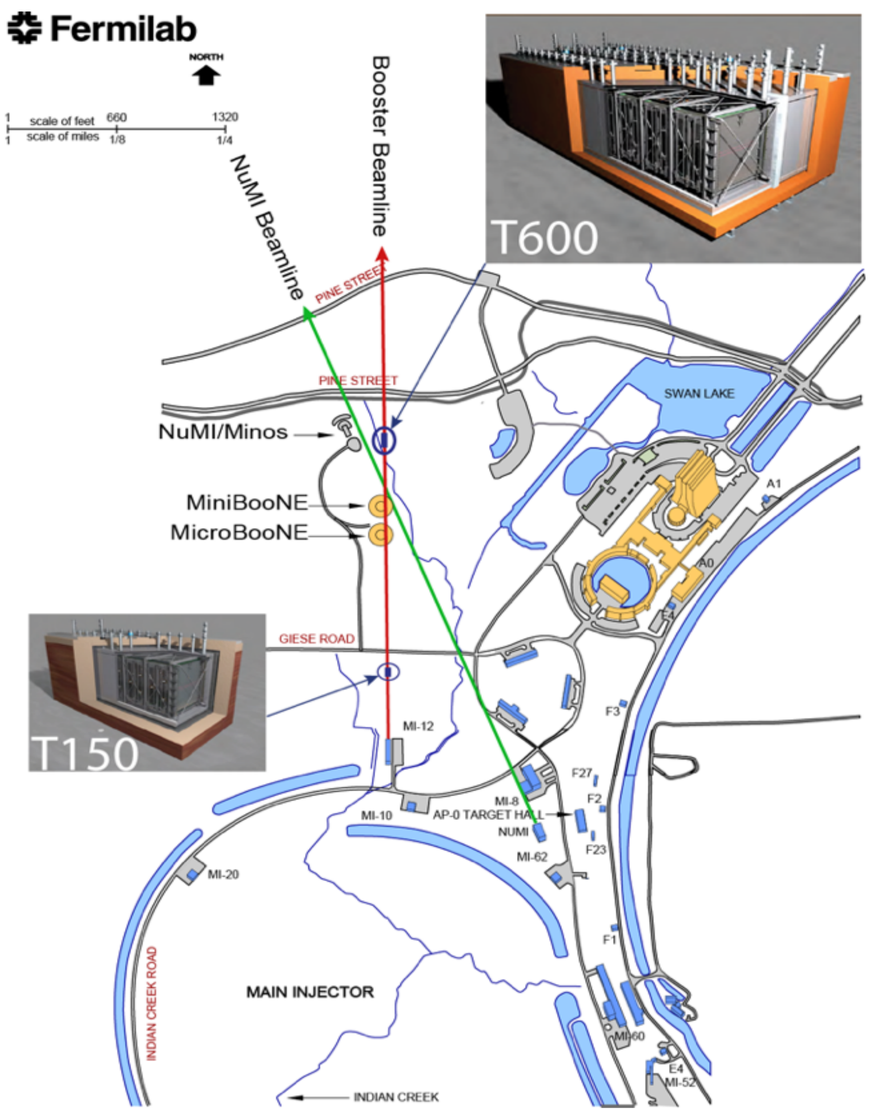
A rate+shape fit with ν_μ+ν_e and correlated near-far systematics has better sensitivity and the international "TripleLAr@FNAL" group is studying this.

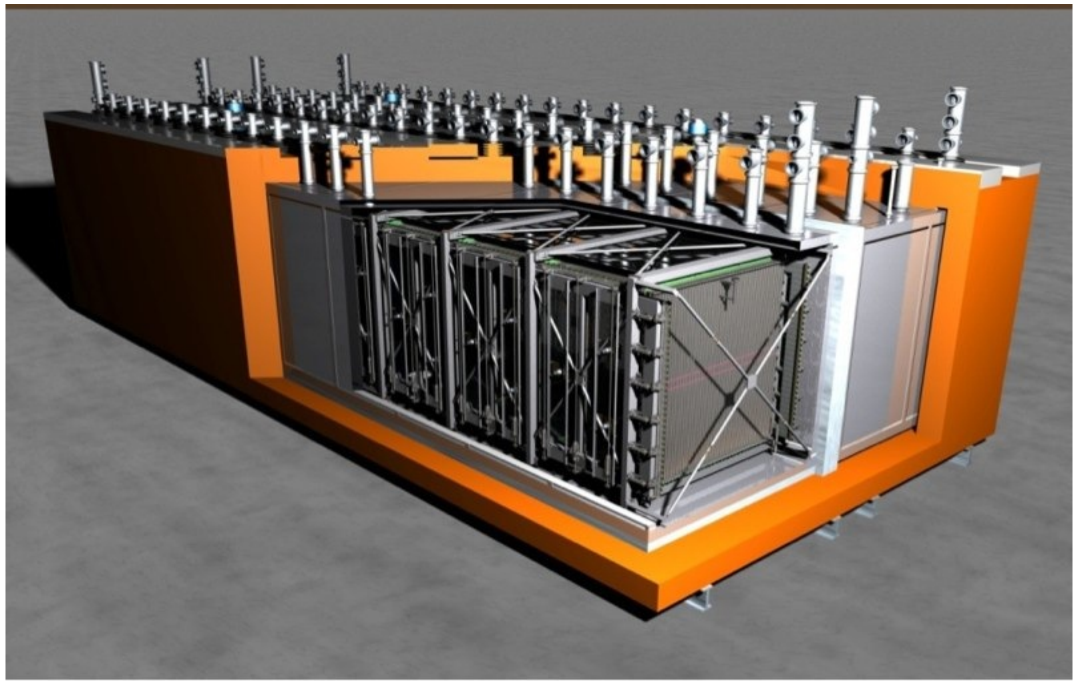
	Primary Channel	Other osc channels	Definitive sterile?	Other physics	Tech R&D?	Cost	Why worry?	Comment
MicroBooNE (π DIF)	$\nu_\mu \to \nu_e$	$\nu_\mu \to \nu_\mu$	—	GeV-scale xsec	Yes	$20M	tech, cosmics	Exists!
LAr1-ND (π DIF)	$\nu_\mu \to \nu_e$	$\nu_\mu \to \nu_\mu$	—	GeV-scale xsec	Yes	$13M	tech, cosmics	

(For the uninitiated, this is a quote from “Jaws”)

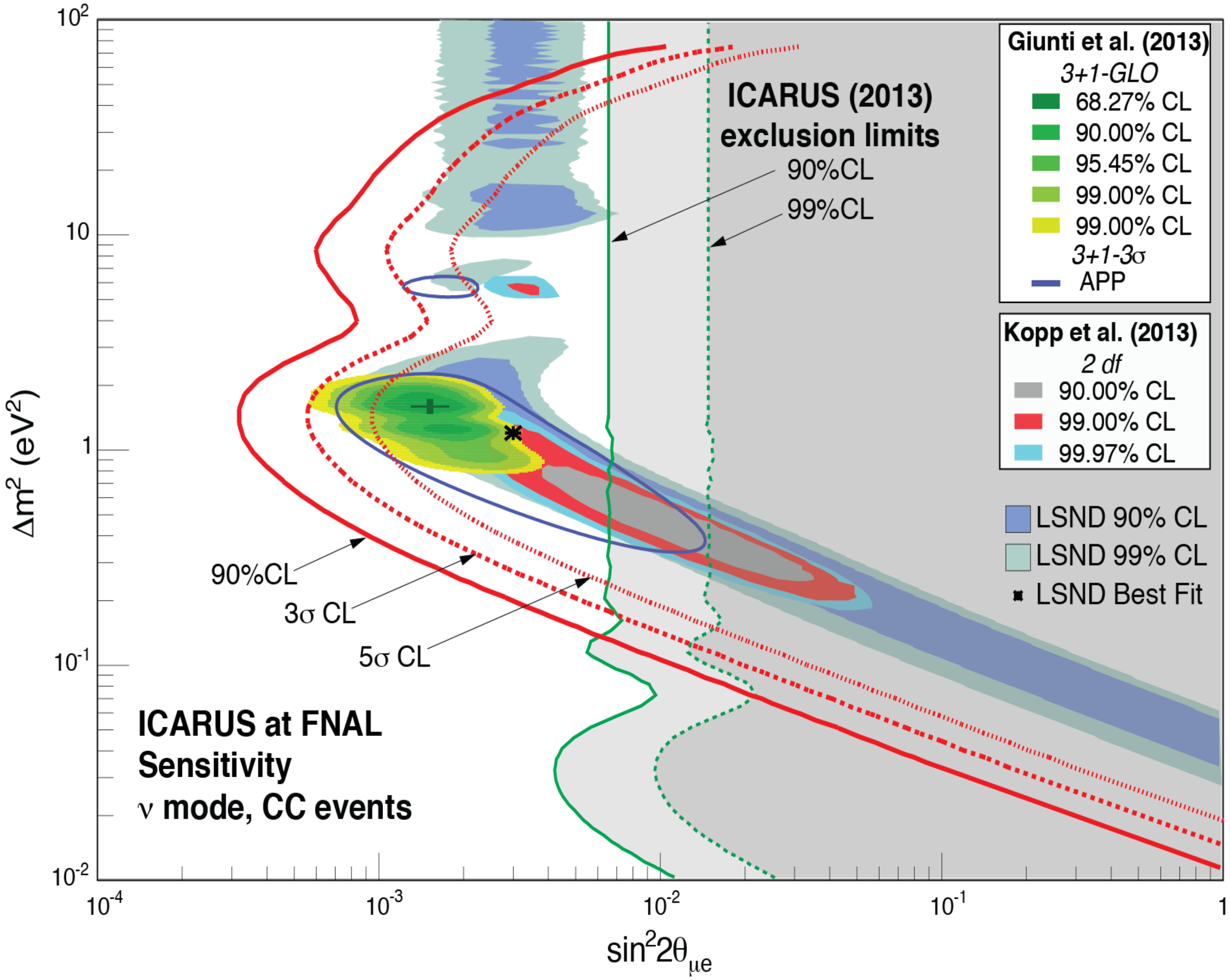
ICARUS @ FNAL

- The T600 (770 ton LArTPC) has recently finished a successful three year run at Gran Sasso, 730 km from the CNGS (~25 GeV beam) at CERN.
- The ICARUS collaboration has formally proposed bringing the T600 to FNAL's BNB, to be combined with a near detector.
- Multiple possible technological upgrades (and LAr R&D): B-field, doping, SiPM light collection, …





ICARUS @ FNAL sensitivity



3 years in neutrino mode with T150 and T600.

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A rate+shape fit with $\nu_\mu + \nu_e$ and correlated near-far systematics has better sensitivity and the international "TripleLAr@FNAL" group is studying this.

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LAr1-ND (π DIF)	$\nu_\mu \to \nu_e$	$\nu_\mu \to \nu_\mu$	—	GeV-scale xsec	Yes	$13M	tech, cosmics	
ICARUS@FNAL (π DIF)	$\nu_\mu \to \nu_e$	$\nu_\mu \to \nu_\mu$	—	GeV-scale xsec	Yes	Under study	tech, cosmics	

	Primary Channel	Other osc channels	Definitive sterile?	Other physics	Tech R&D?	Cost	Why worry?	Comment
MicroBooNE (π DIF)	$\nu_\mu \rightarrow \nu_e$	$\nu_\mu \rightarrow \nu_\mu$		GeV-scale xsec	Yes	\$20M	tech, cosmics	Exists!
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ICARUS@FNAL (π DIF)	$\nu_\mu \rightarrow \nu_e$	$\nu_\mu \rightarrow \nu_\mu$		GeV-scale xsec	Yes	Under study	tech, cosmics	
TripleLAr@FNAL (π DIF)	$\nu_\mu \rightarrow \nu_e$ $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	$\nu_\mu \rightarrow \nu_\mu$ $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$	Probably	GeV-scale xsec	Yes	Under study	tech, cosmics	Work in progress. Anti-nu?

*All of the right ingredients in TripleLAr@FNAL (near, mid, big far) are coming together for a definitive test.

OscSNS, the LSND approach

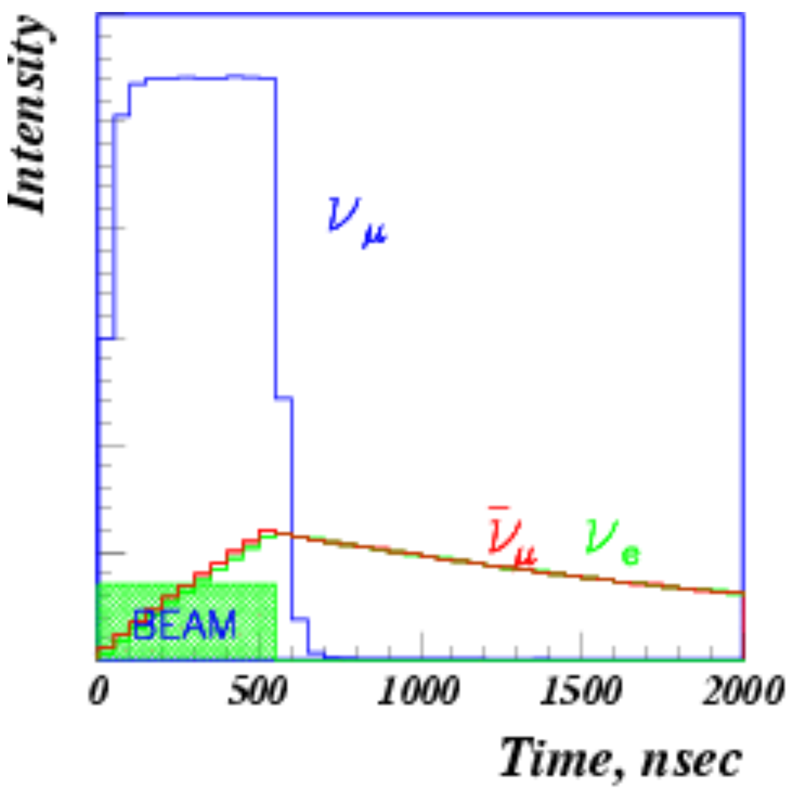
- There is a reason the LSND anomaly still exists almost 15 years later. **It was a pretty sensitive experiment!**

- The Spallation Neutron Source at Oak Ridge, by far the most intense source of non-reactor neutrinos in the world (1.4 MW of protons on target) is completely wasted as far as neutrino physics goes! Remember that the BNB is ~32 kW of protons (in an admittedly apples-to-oranges comparison)!

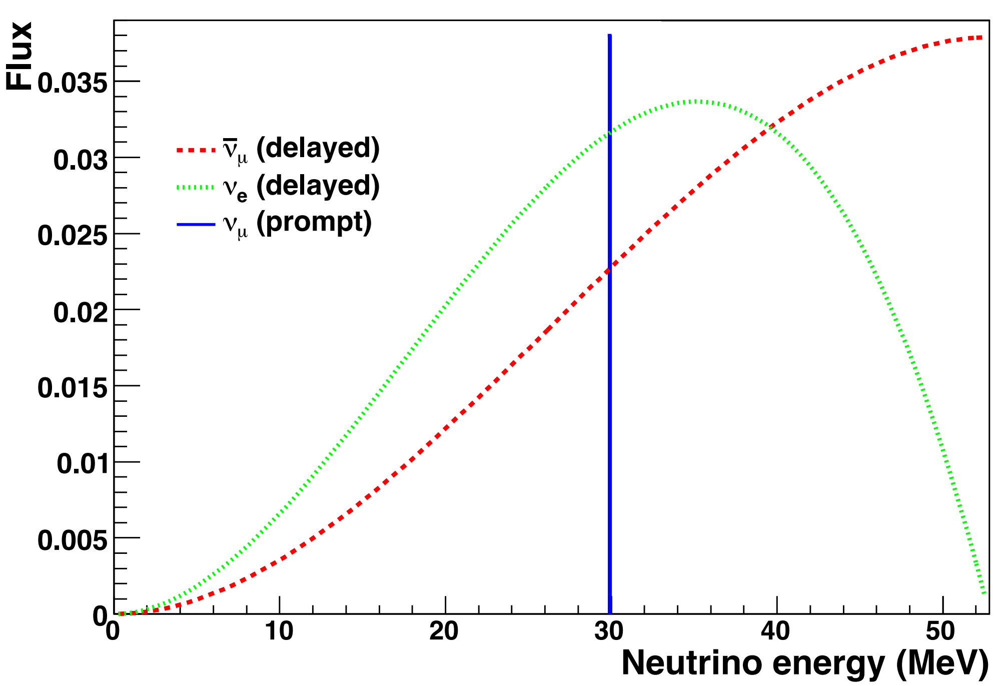
- If you can rule out LSND with an LSND-style experiment, you have definitively resolved the sterile neutrino issue.

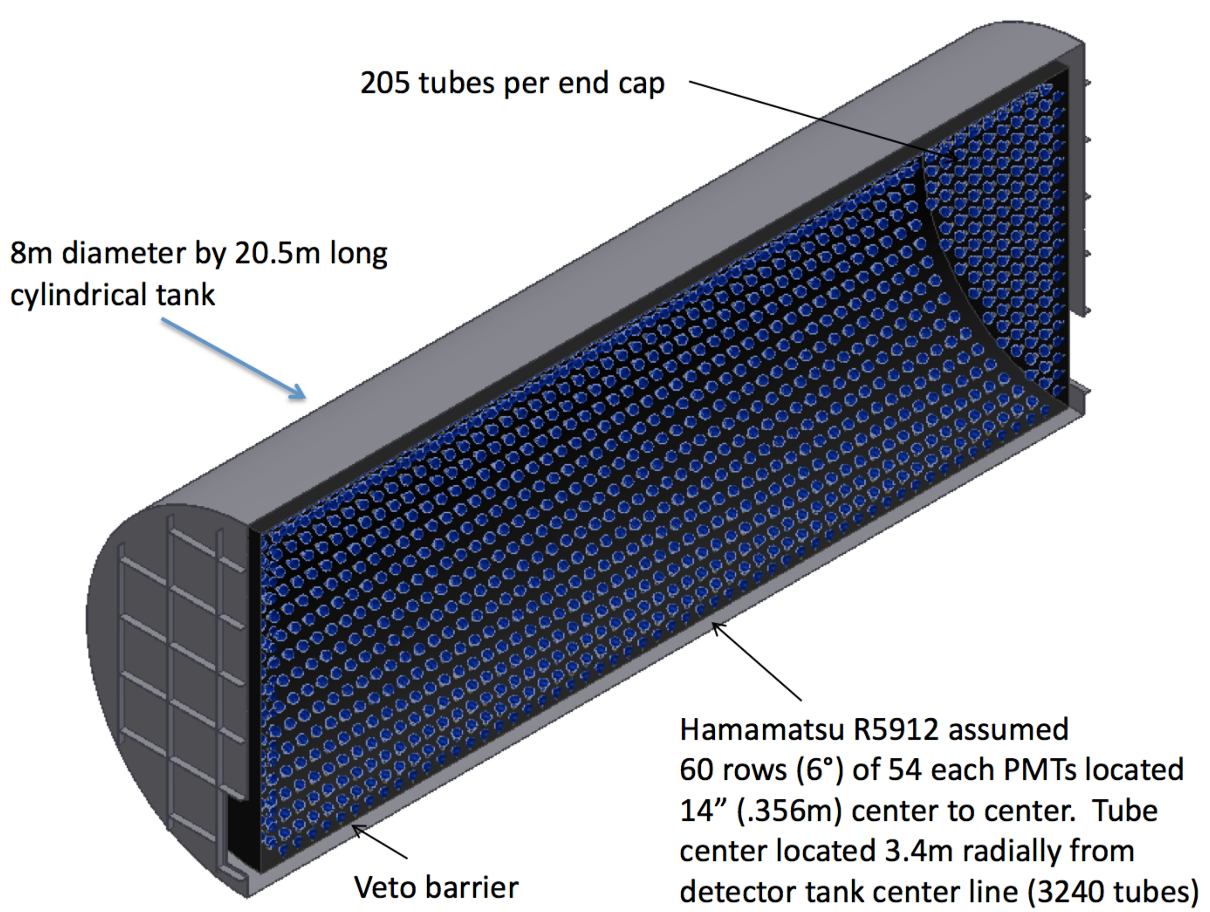
- If you can rule out LSND with a pion DIF experiment in neutrino mode, there still may be questions. See: differences between neutrinos and anti-neutrinos.

OscSNS



- A proposed LSND-style decay-at-rest experiment at the 1.4 MW SNS (1 GeV protons on an Hg target).
- Can provide *definitive* coverage of the sterile neutrino region with an 800 ton LS detector, 60 m away.

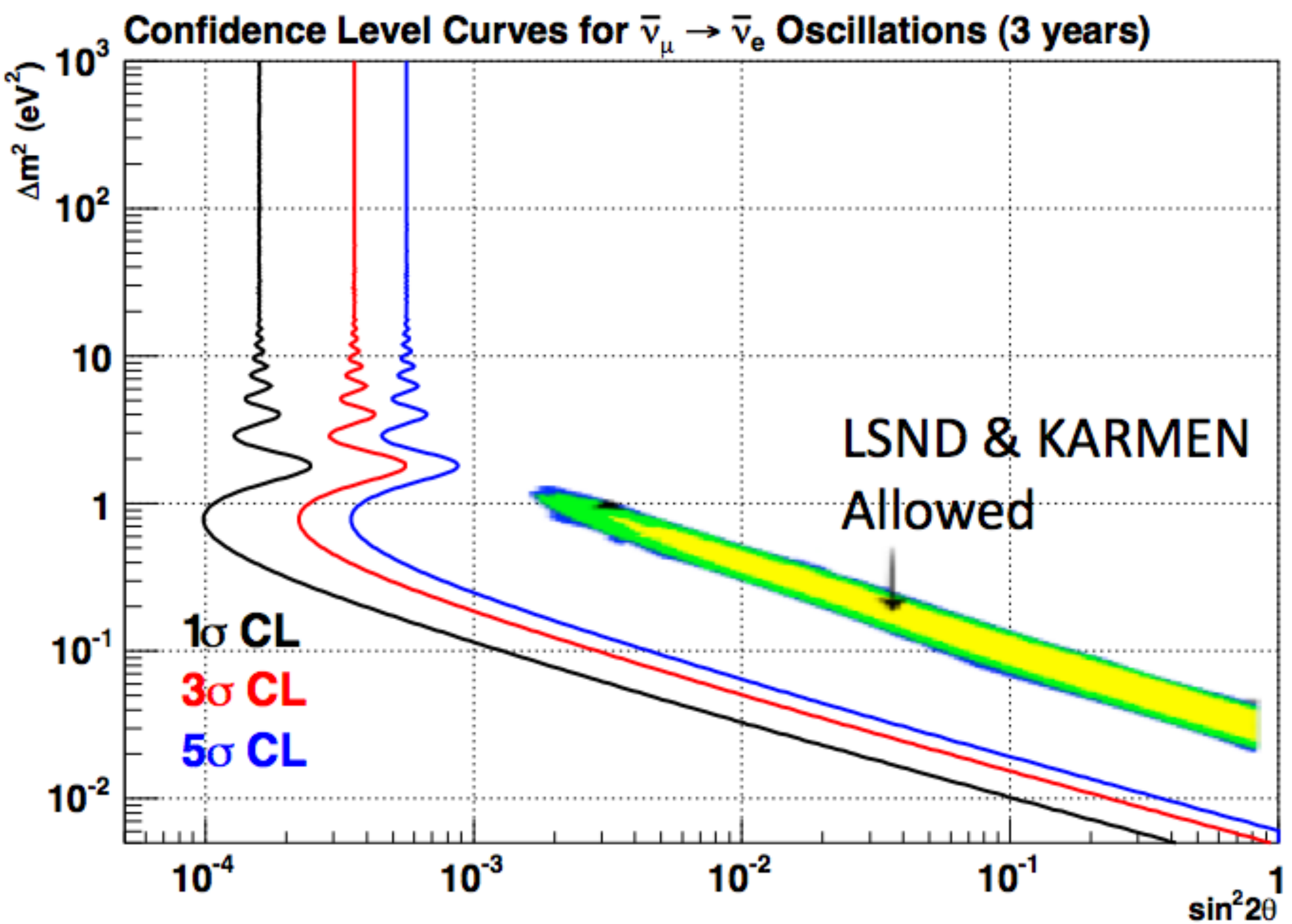




OscSNS seems to solve all of the usual quibbles about LSND

	LSND	OscSNS	Notes
Baseline	30 m	60 m	Reduced in-beam background
Orientation	Detector in front of beam	Detector behind beam	Reduced in-beam background
Beam power	0.8 MW	1.4 MW	
Beam pulse	600 μs,120Hz	695 ns, 60 Hz	Reduced steady-state background
Beam kinetic energy	798 MeV	1000 MeV	
Detector mass	167 ton	800 ton	
Detector technology	Liq. scint. w/ 25% photocoverage	Liq. scint. w/ 25% photocoverage	Better PMT QE expected in OscSNS

OscSNS sensitivity



OscSNS White Paper, arXiv:1307.7097

	Primary Channel	Other osc channels	Definitive sterile?	Other physics	Tech R&D?	Cost	Why worry?	Comment
MicroBooNE (π DIF)	$\nu_\mu \to \nu_e$	$\nu_\mu \to \nu_\mu$		GeV-scale xsec	Yes	$20M	tech, cosmics	Exists!
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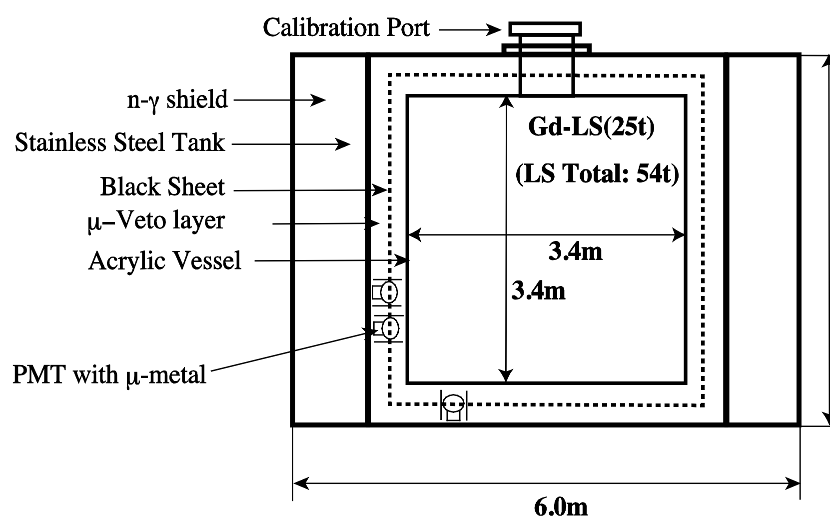
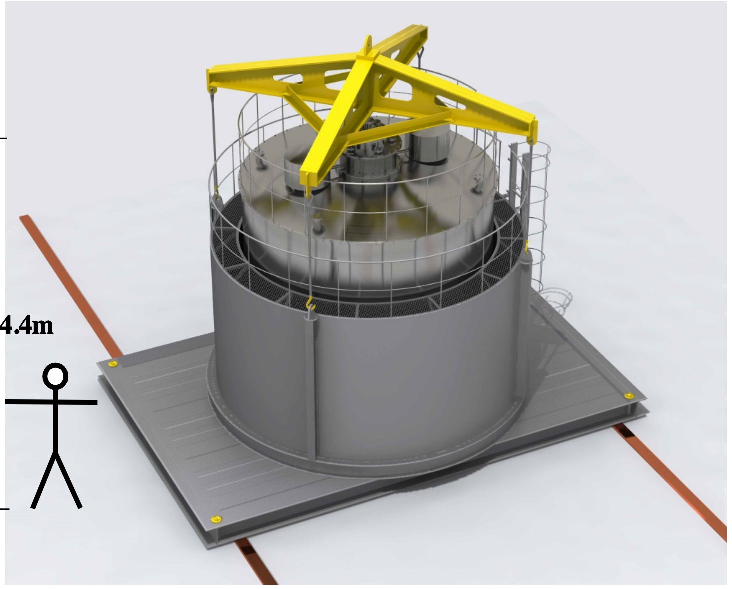
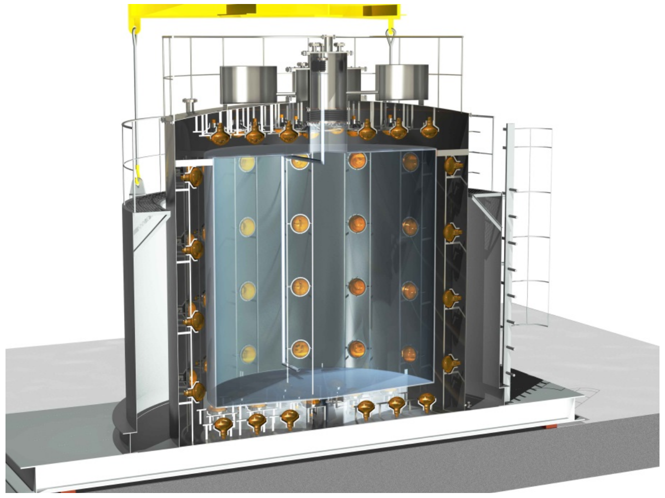
TripleLAr@FNAL (π DIF)	$\nu_\mu \to \nu_e$ $\bar{\nu}_\mu \to \bar{\nu}_e$	$\nu_\mu \to \nu_\mu$ $\bar{\nu}_\mu \to \bar{\nu}_\mu$	Probably	GeV-scale xsec	Yes	Under study	tech, cosmics	Work in progress. Anti-nu?
OscSNS (π,μ DAR)	$\bar{\nu}_\mu \to \bar{\nu}_e$	$\nu_e \to \nu_e$	Yes	Supernova xsec	No	$20M	intrinsic $\bar{\nu}_e$	

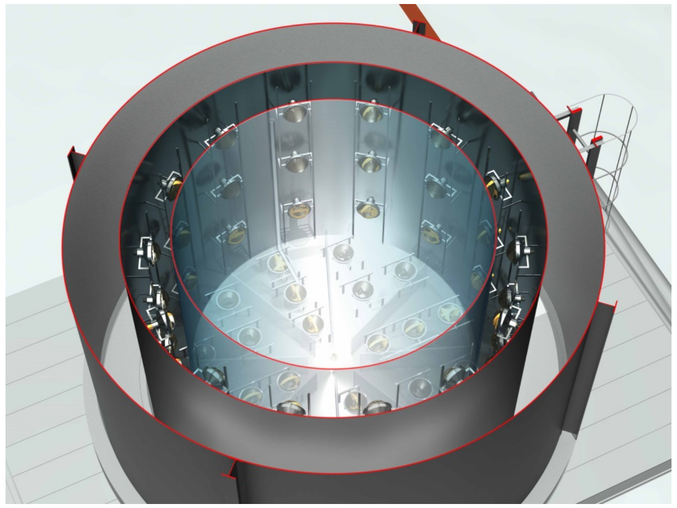
JPARC-MLF

- The JPARC-MLF experiment is very similar to OscSNS.
- An eventually 1 MW spallation source, with 3 GeV protons on a Hg target.
- Phased approach with “Phase 1” proposal to put 2x25ton Gd-LS detectors 17 m away from the source to do an LSND-style experiment.



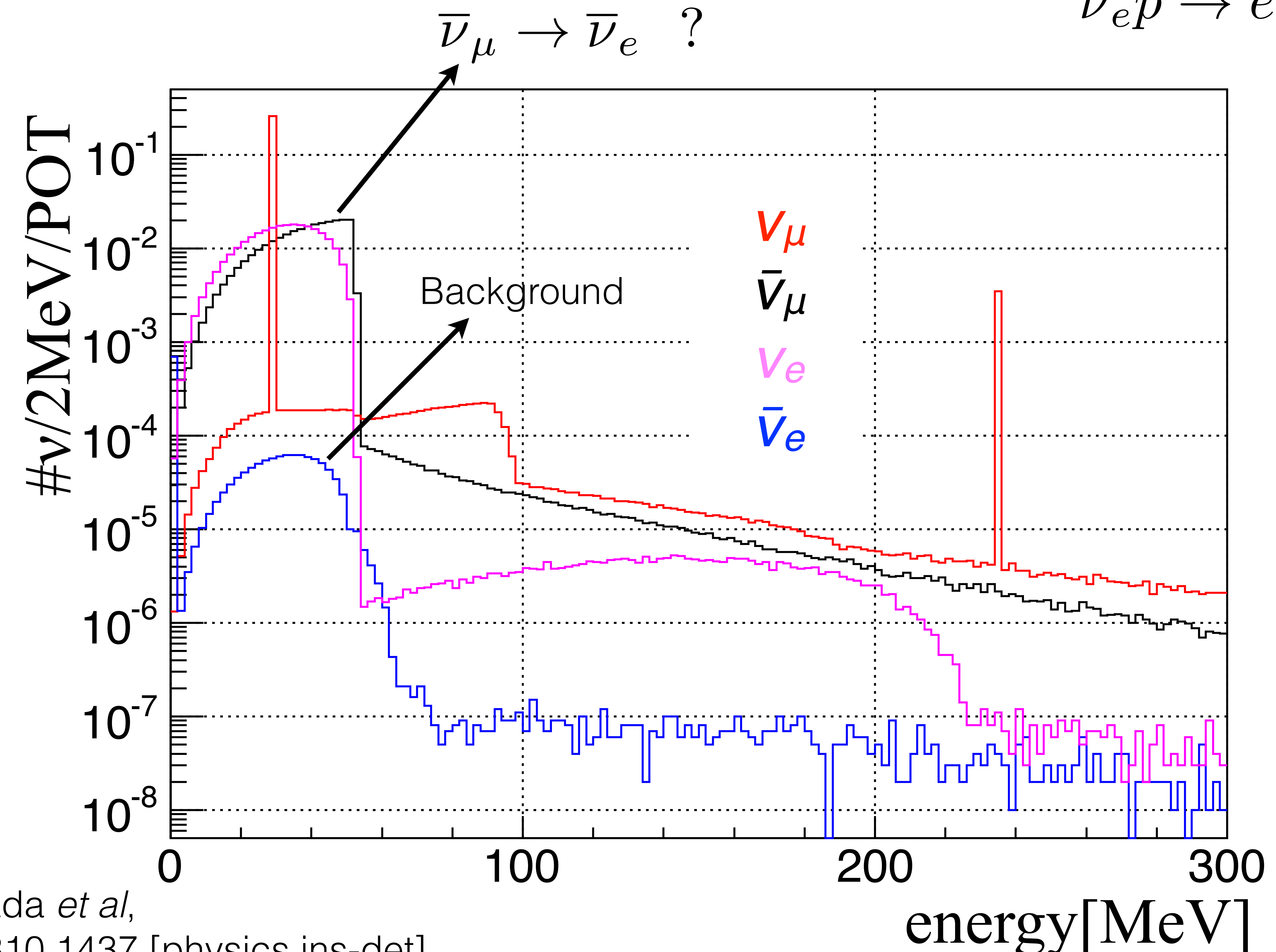






LSND-style

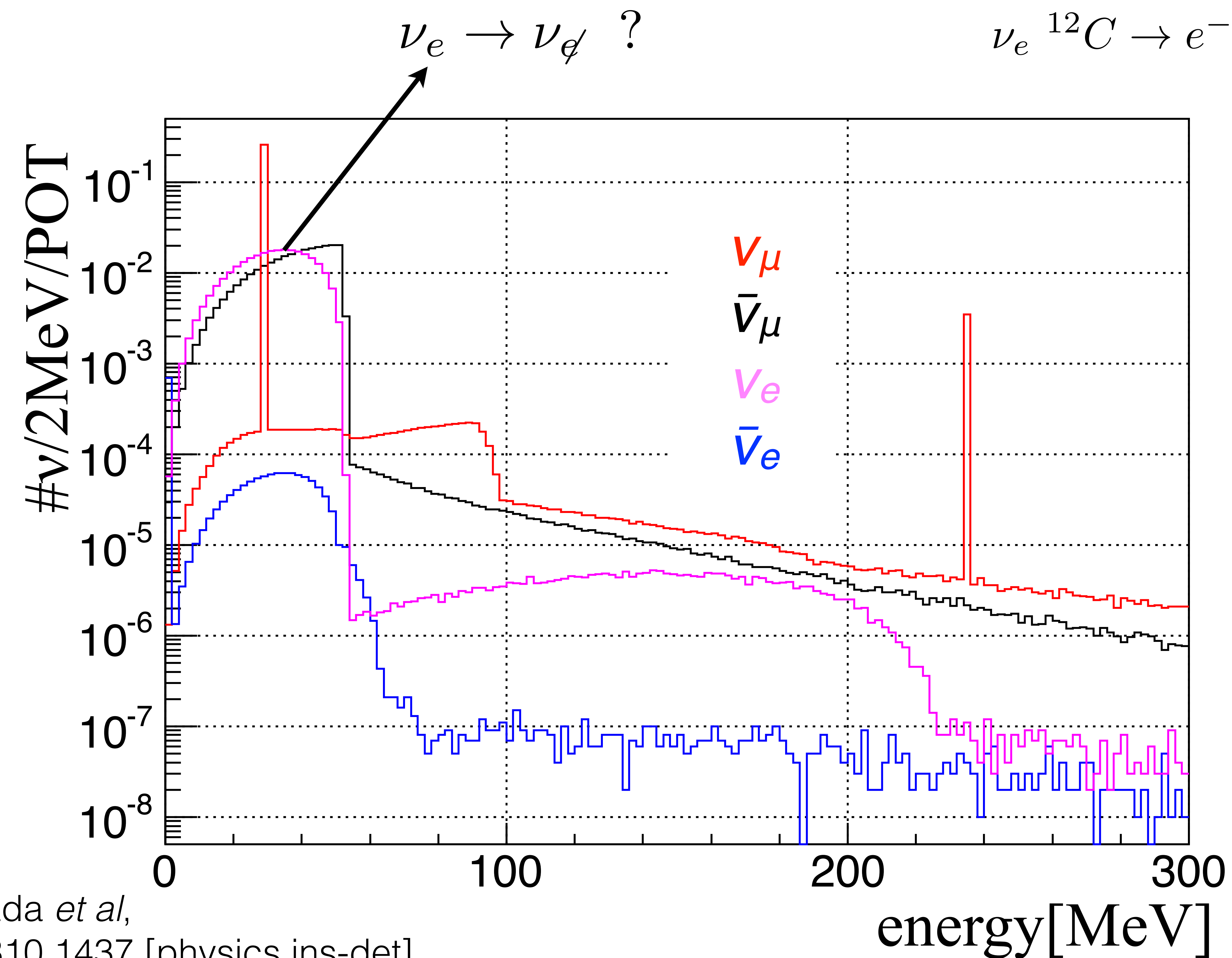
Detect with:
$\overline{\nu}_e p \rightarrow e^+ n$



M. Harada *et al*,
arXiv:1310.1437 [physics.ins-det]

Electron disappearance

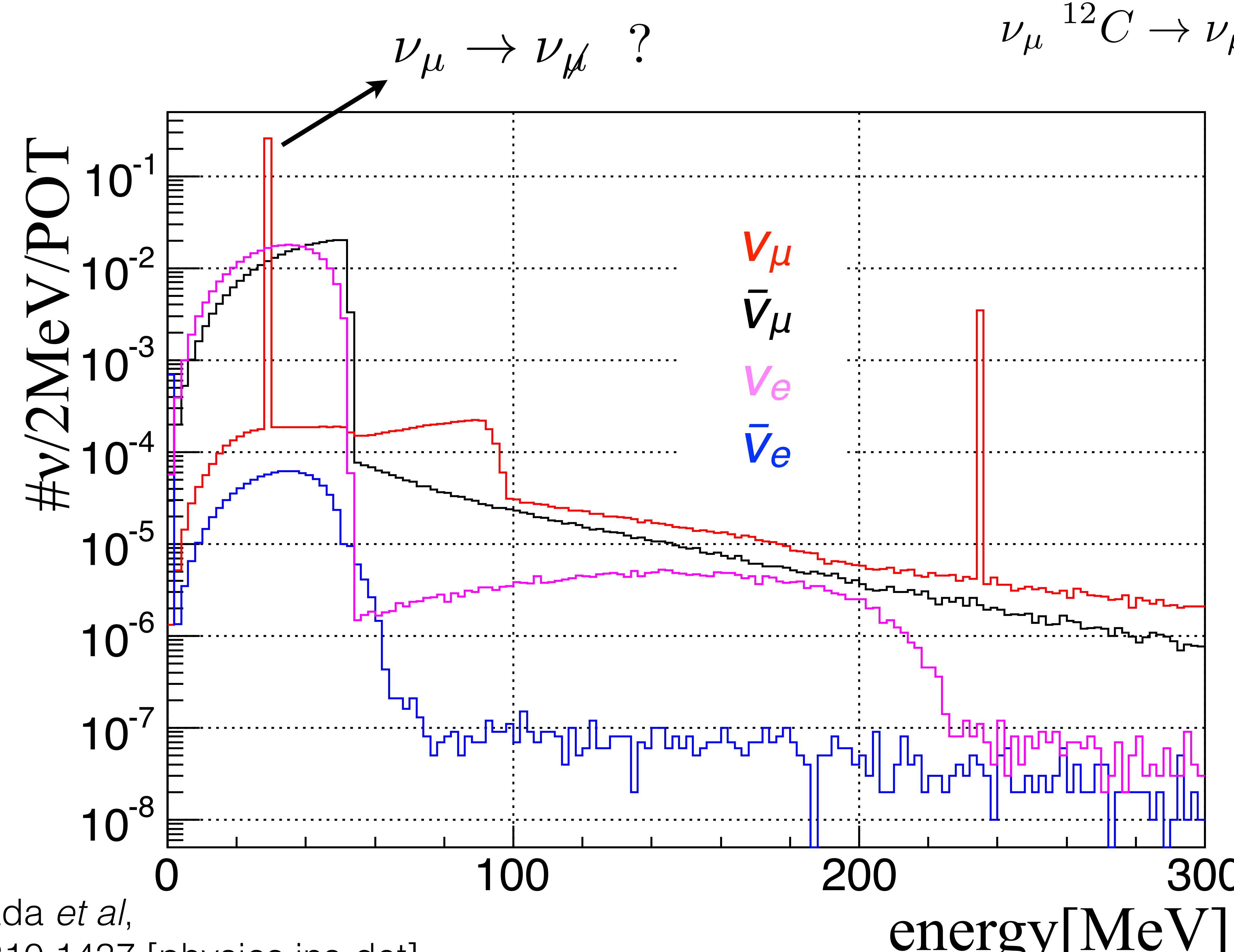
Detect with:
$\nu_e \ ^{12}C \to e^- \ ^{12}N_{gs}$



M. Harada *et al*,
arXiv:1310.1437 [physics.ins-det]

Neutral current disappearance

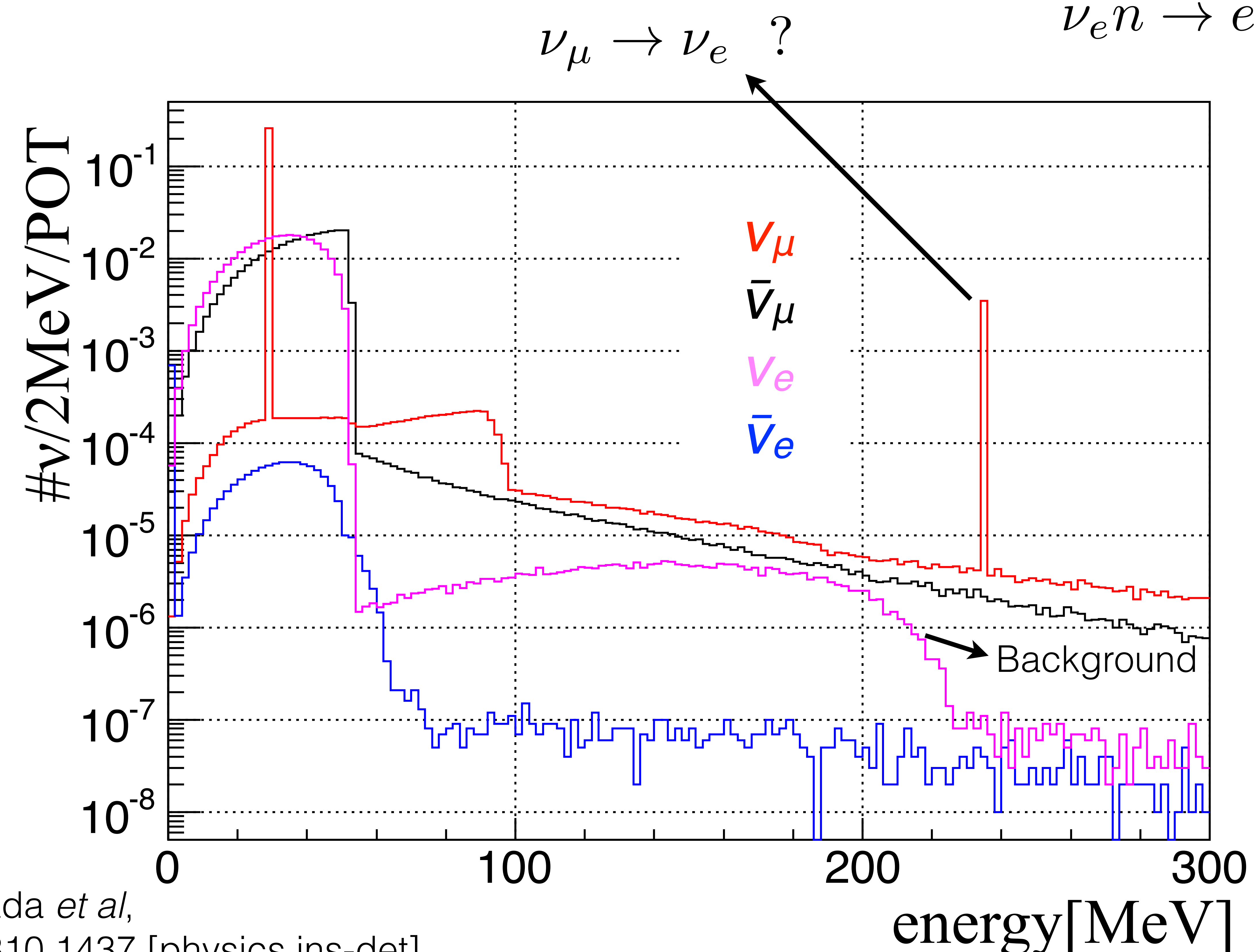
Detect with:
$\nu_\mu \ {}^{12}C \to \nu_\mu \ {}^{12}C^*$



M. Harada *et al*,
arXiv:1310.1437 [physics.ins-det]

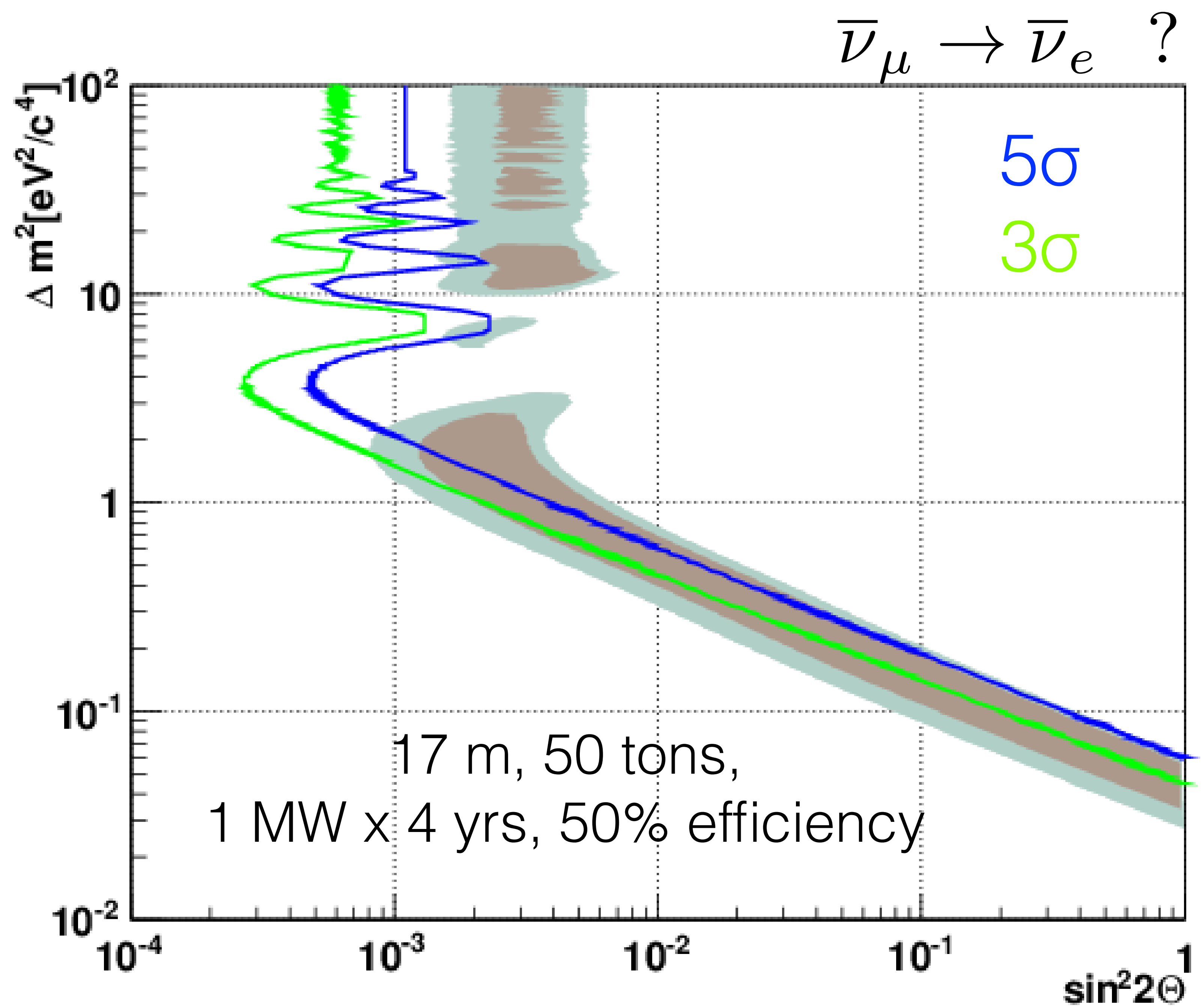
Kaon decay-at-rest

Detect with:
$\nu_e n \rightarrow e^- p$



M. Harada *et al*,
arXiv:1310.1437 [physics.ins-det]

JPARC-MLF sensitivity



"Phase 1"

M. Harada *et al*,
arXiv:1310.1437 [physics.ins-det]

	Primary Channel	Other osc channels	Definitive sterile?	Other physics	Tech R&D?	Cost	Why worry?	Comment
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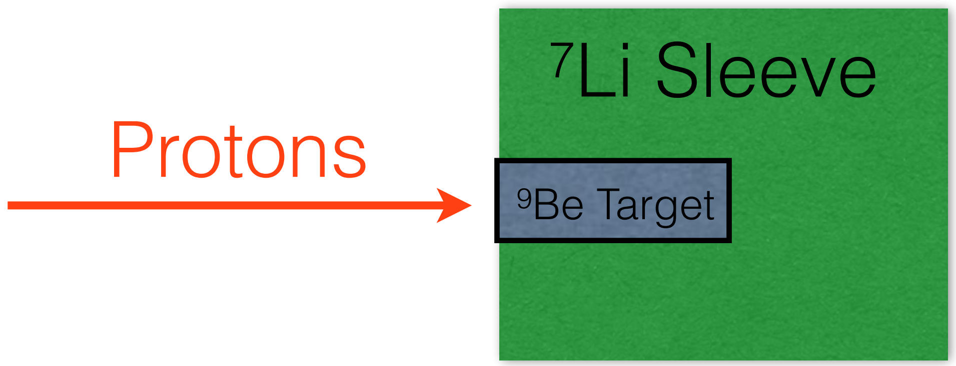
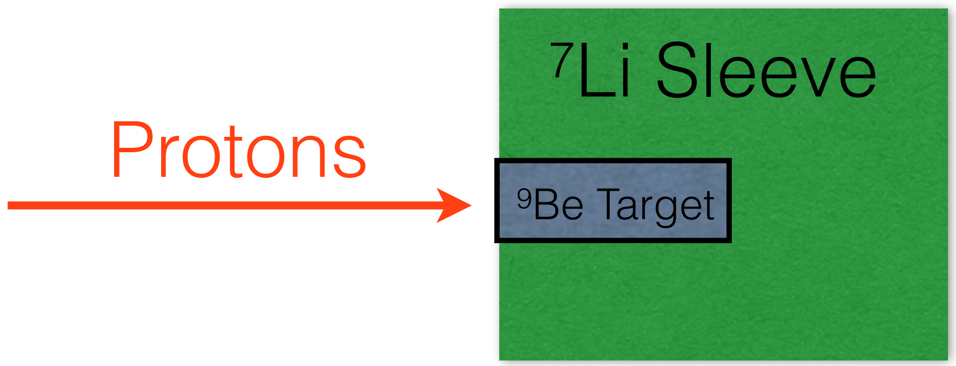
IsoDAR

(doubling as the injector cyclotron design for the DAEδALUS δ_{CP} experiment)



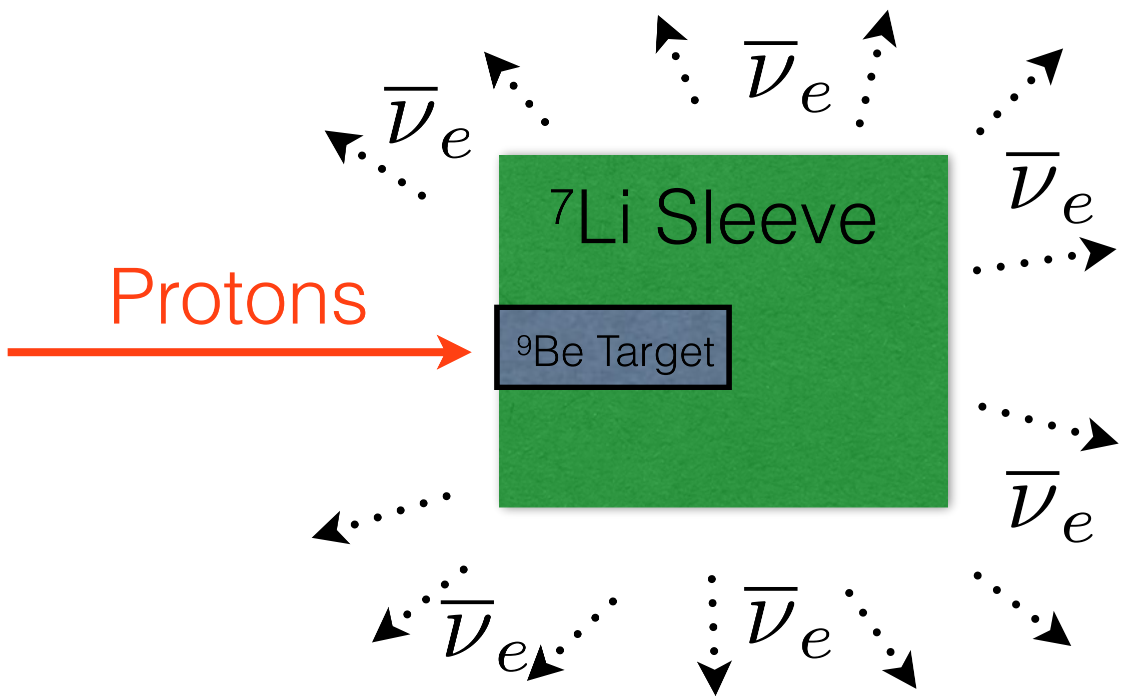
IsoDAR



$$p + {}^9\mathrm{Be} \to \boxed{{}^8\mathrm{Li}} + 2p$$

$$p + {}^9\mathrm{Be} \to {}^9\mathrm{B} + n$$
$$n + {}^7\mathrm{Li} \to \boxed{{}^8\mathrm{Li}} + \gamma$$

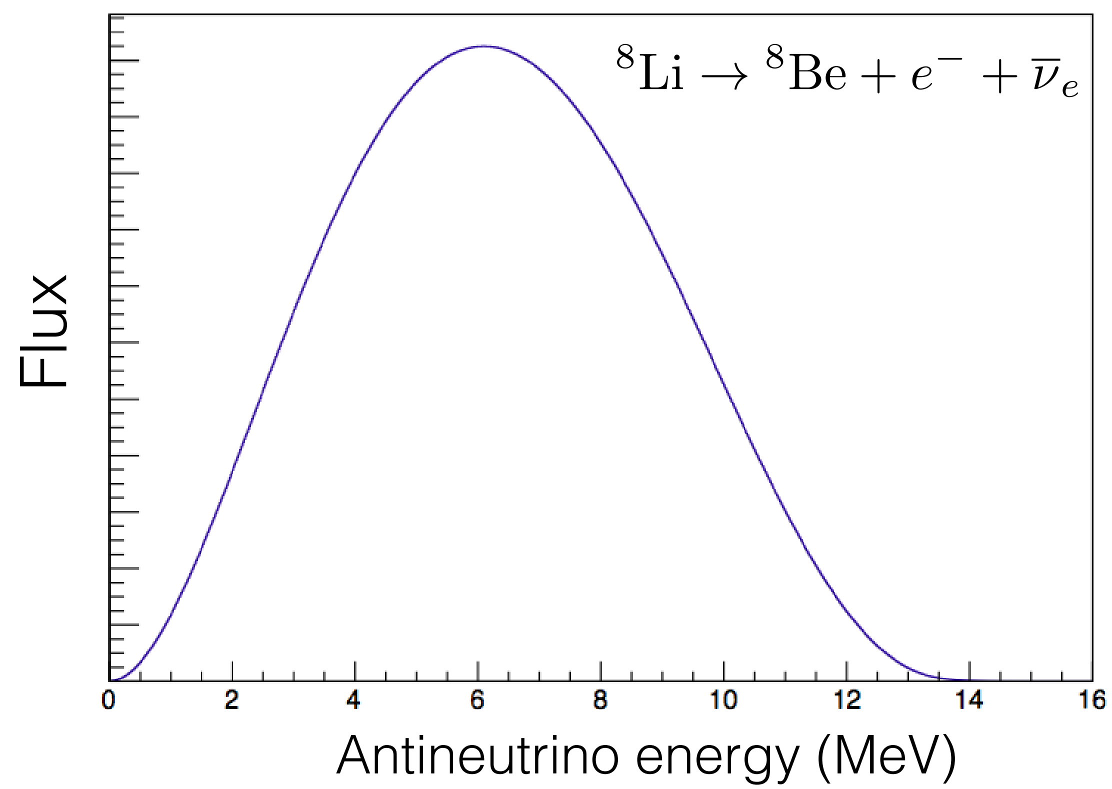
IsoDAR



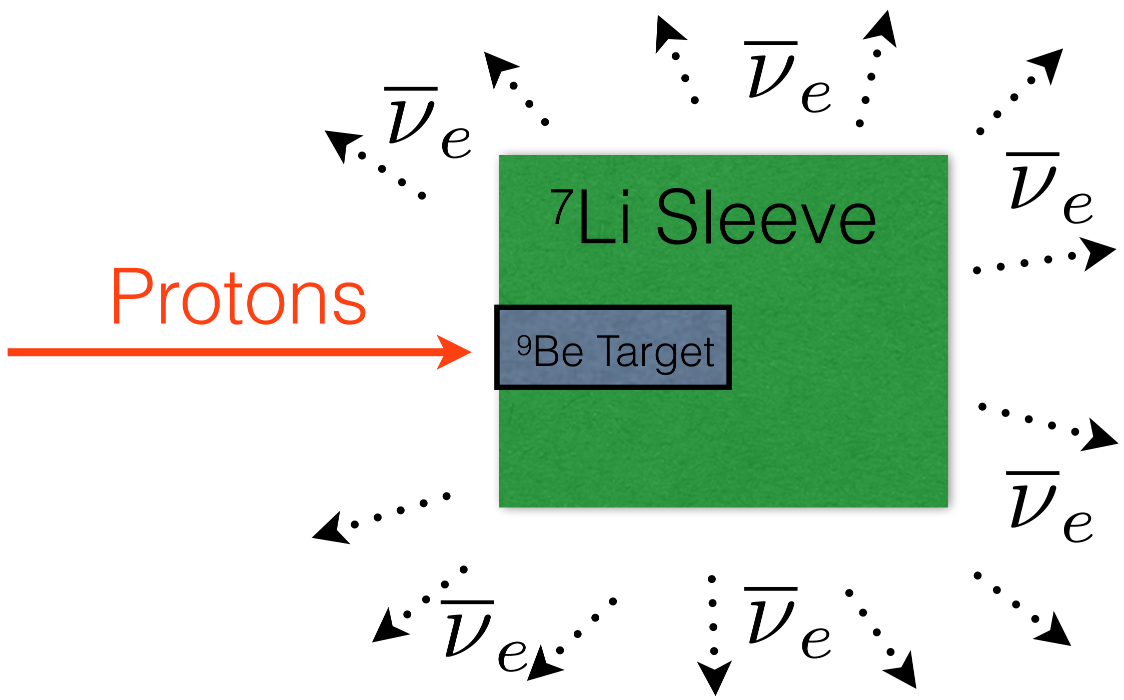
$$p + {}^9\mathrm{Be} \rightarrow \boxed{{}^8\mathrm{Li}} + 2p$$

$$p + {}^9\mathrm{Be} \rightarrow {}^9\mathrm{B} + n$$
$$n + {}^7\mathrm{Li} \rightarrow \boxed{{}^8\mathrm{Li}} + \gamma$$

$$^8\mathrm{Li} \rightarrow {}^8\mathrm{Be} + e^- + \boxed{\overline{\nu}_e}$$

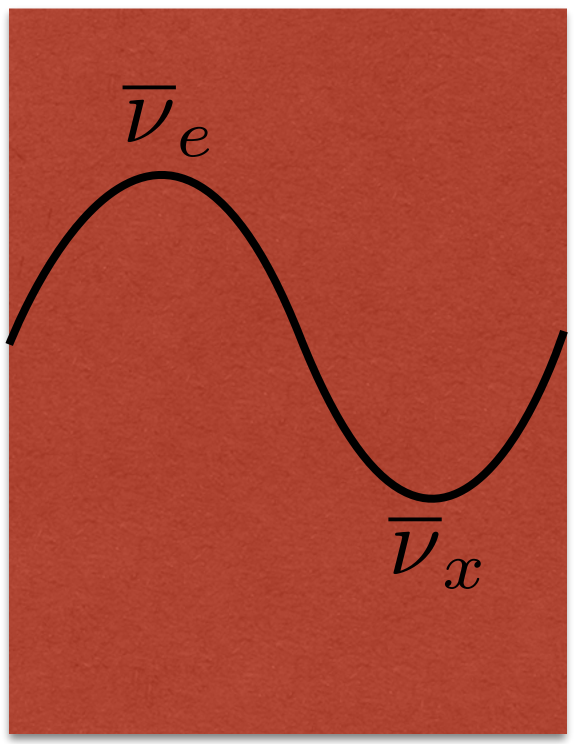


IsoDAR



$$\overline{\nu}_e \to \overline{\nu}_x \quad ?$$

Detector



$$\overline{\nu}_e p \to e^+ n$$

$$p + {}^9\mathrm{Be} \to \boxed{{}^8\mathrm{Li}} + 2p$$

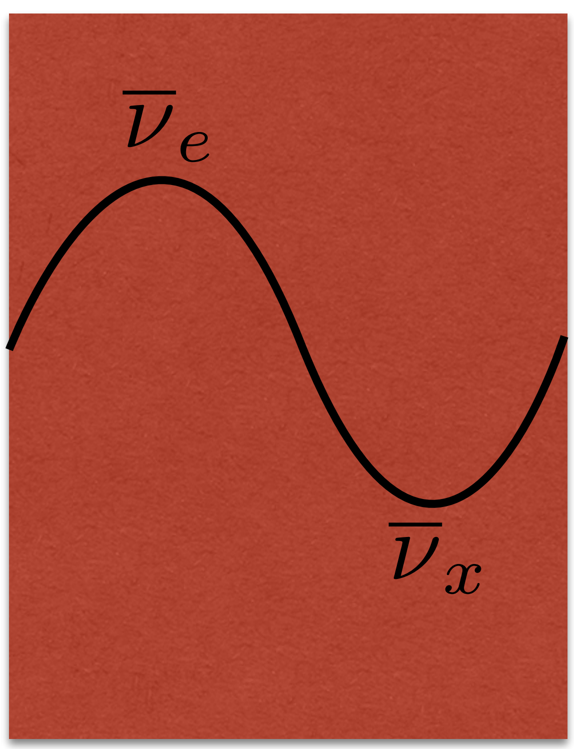
$$p + {}^9\mathrm{Be} \to {}^9\mathrm{B} + n$$
$$n + {}^7\mathrm{Li} \to \boxed{{}^8\mathrm{Li}} + \gamma$$

$$ {}^8\mathrm{Li} \to {}^8\mathrm{Be} + e^- + \boxed{\overline{\nu}_e}$$

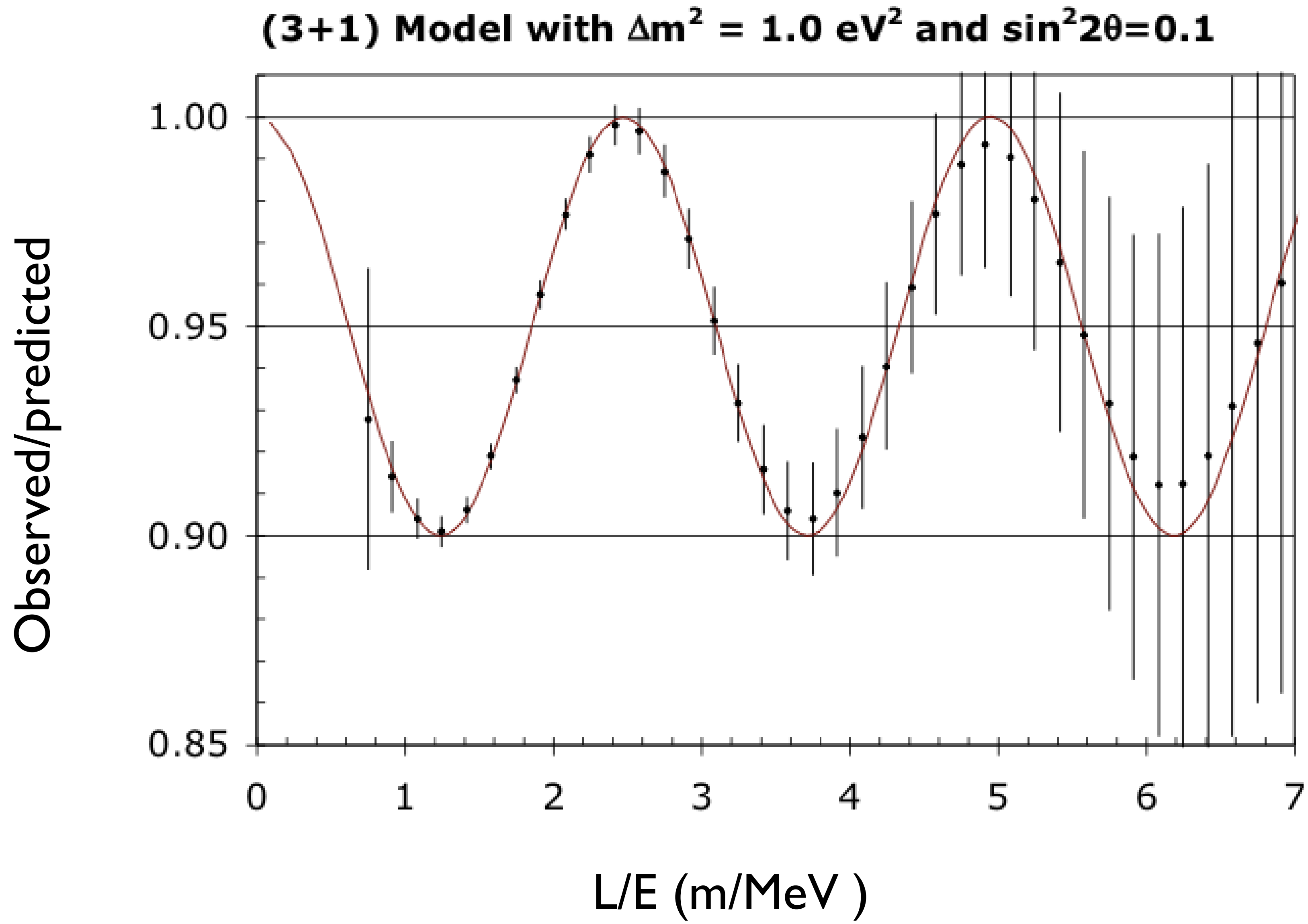
IsoDAR

$$\overline{\nu}_e \rightarrow \overline{\nu}_x \quad ?$$

Detector

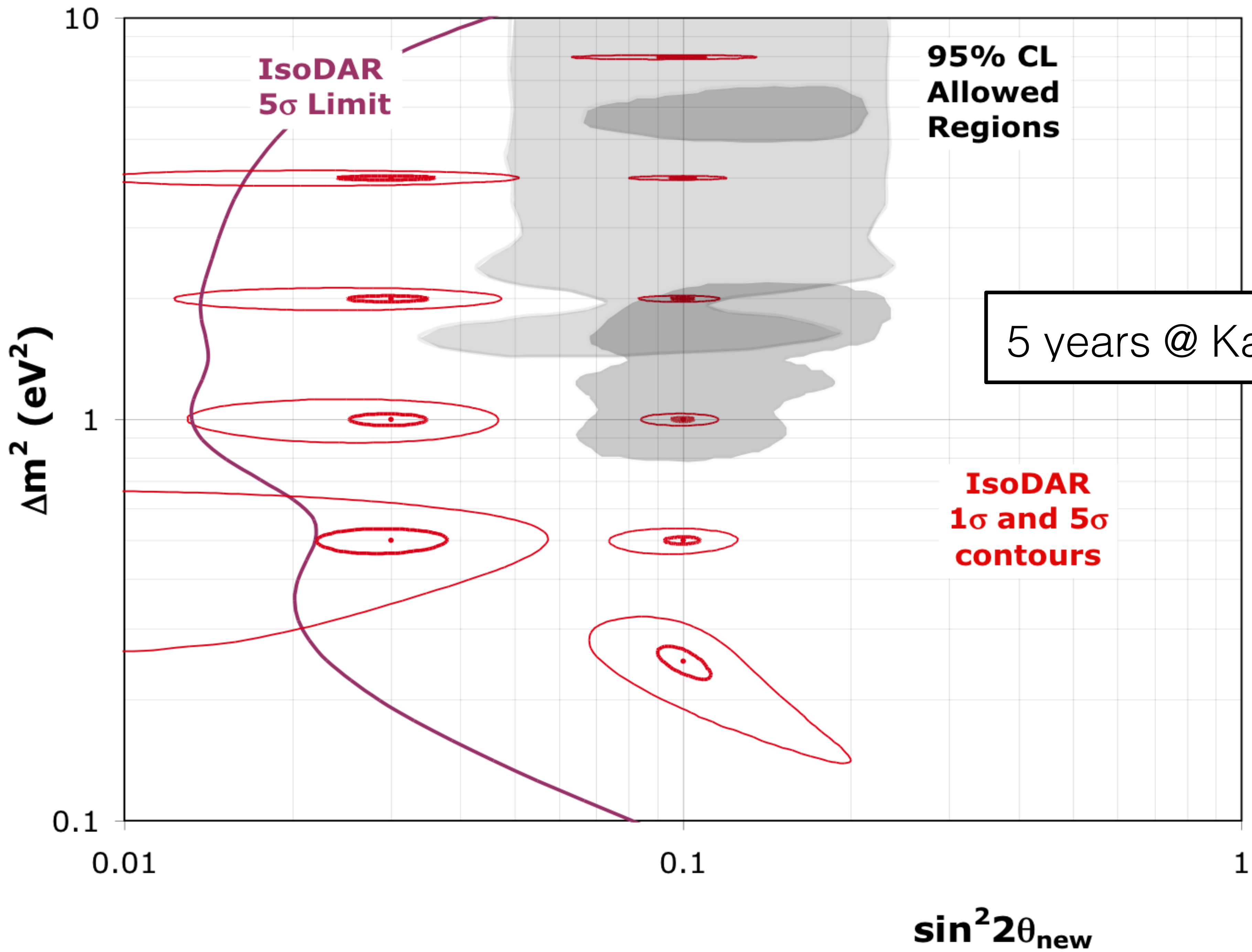


$$\overline{\nu}_e p \rightarrow e^+ n$$



820,000 IBD events in 5 years at KamLAND
(16 m baseline to center of detector)

IsoDAR abilities



5 years @ KamLAND

By the way, this is really an excellent plot that I think should be more common in the sterile neutrino field. If we see something, how well can we measure it?

	Primary Channel	Other osc channels	Definitive sterile?	Other physics	Tech R&D?	Cost	Why worry?	Comment
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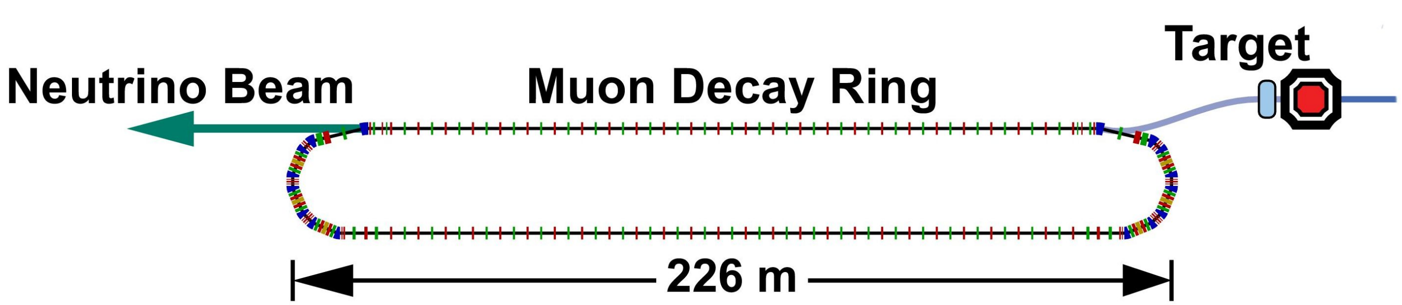
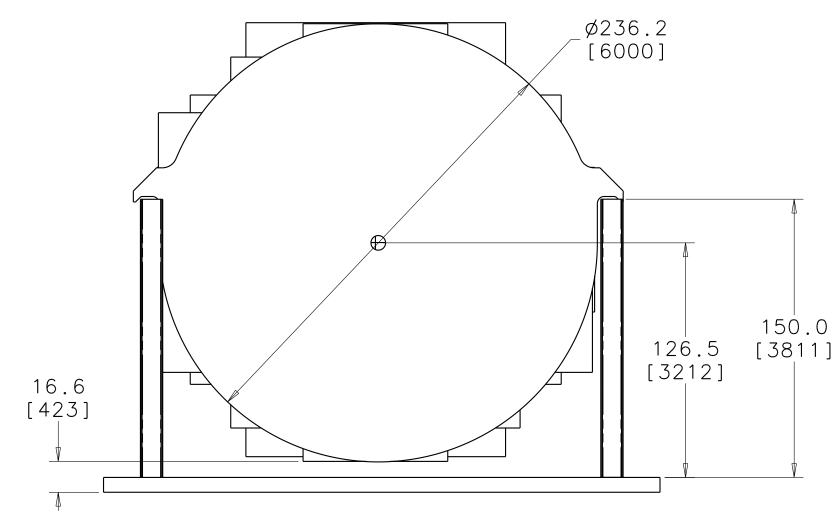
IsoDAR-KamLAND (Isotope DAR)	$\bar{\nu}_e \rightarrow \bar{\nu}_e$	-	Yes	$\bar{\nu}_e e^-$ (electroweak)	Yes	\$30M	timeline, tech	

nuSTORM

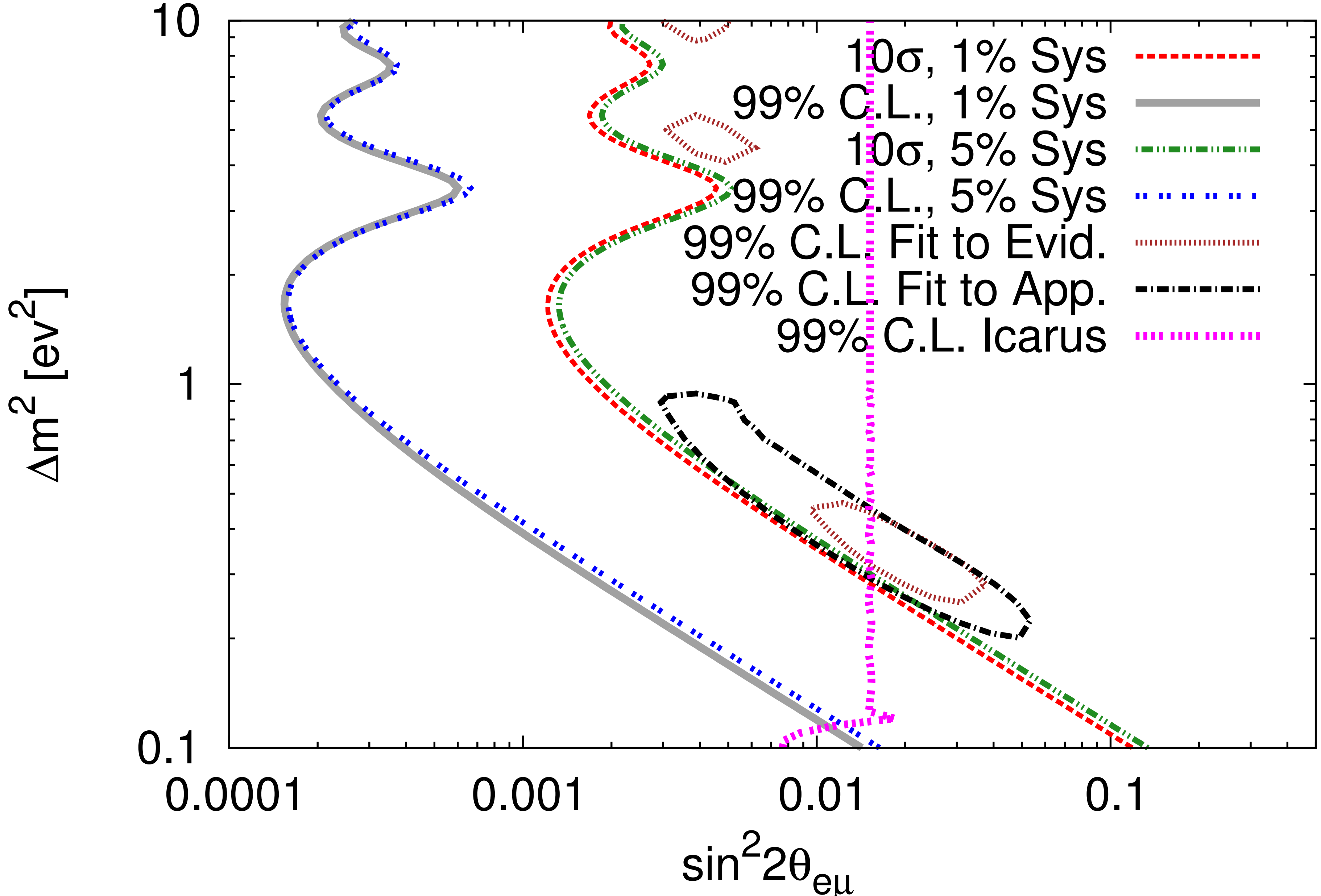
- A low-energy (P_μ=3.8 GeV/c) muon storage ring in combination with a LAr or Fe+scintillator detector.
- Can provide *definitive* coverage of the sterile neutrino region.
- Important technology step: muon storage ring as a simple neutrino factory.





A prospective iron-scintillator detector for nuSTORM

nuSTORM sensitivity



D. Adey *et al.*,
arXiv:1402.5250

1.3 kton magnetized Fe-scintillator far detector @ 2km
(w/ near detector @ 100 m); 10 years of running

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nuSTORM (μ DIF)	$\nu_e \to \nu_\mu$	$\bar{\nu}_\mu \to \bar{\nu}_\mu$ $\nu_e \to \nu_e$	Yes	GeV-scale xsec	Yes	$300M	timeline, tech, cost	P5 says no

Conclusions

- **The discovery of a light sterile neutrino would be a monumental result for particle physics and cosmology.**

- The light sterile neutrino issue needs to be resolved.
- A truly definitive resolution is difficult to achieve and will likely require multiple detectors/experiments.
- Regardless if there is a sterile neutrino or not, a lot of important physics and R&D can be provided by accelerator-based short-baseline experiments.

Thanks to

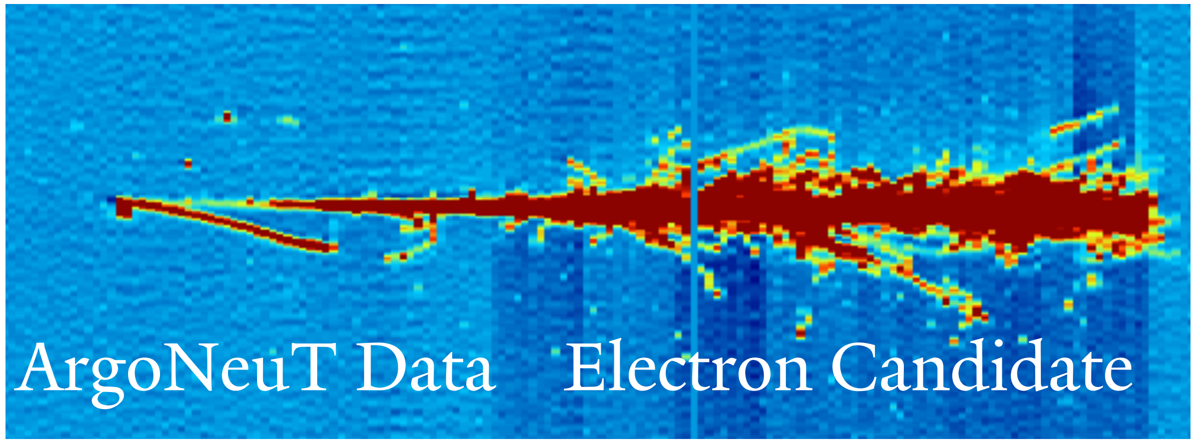
L. Bugel, G. Collin, J. Conrad, G. Feldman, B. Fleming, A. Guglielmi, B. Jones, B. Kayser, S. Kayser, W. Louis, T. Maruyama, Z. Moss, O. Palamara, H. Ray, D. Schmitz, M. Shaevitz, M. Soderberg, D. Winklehner

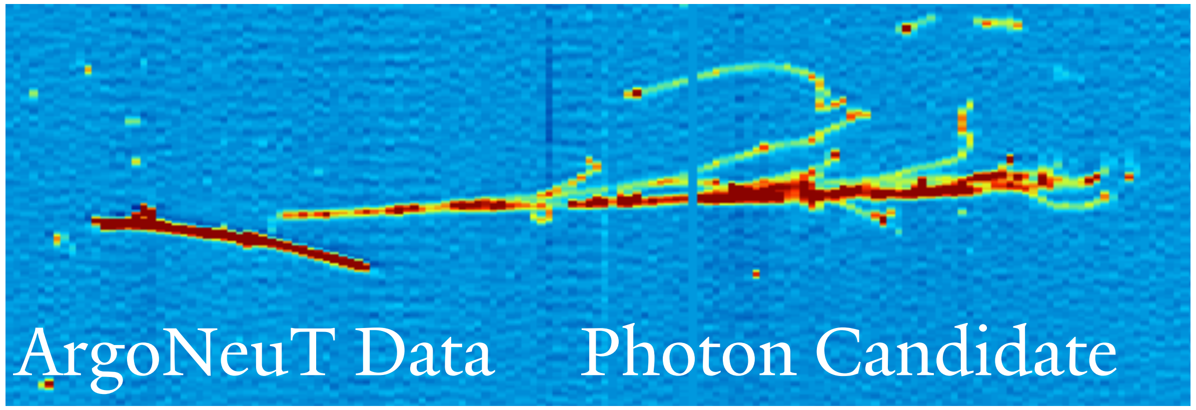
Backup

Note: this picture is apparently not real (Photoshop)

LArTPC technology

- MiniBooNE has drawn closed contours but cannot tell us if the allowed regions correspond to a photon or an electron excess. Electrons make it more likely that the excess is due to oscillations; gammas make it more likely that the excess is due to a new or underestimated background.
- LArTPCs will be able to make this distinction and, in general, are **simply able to characterize the nature of a neutrino beam much better than more conventional technology**.





Advantage of the neutral current in a sterile search

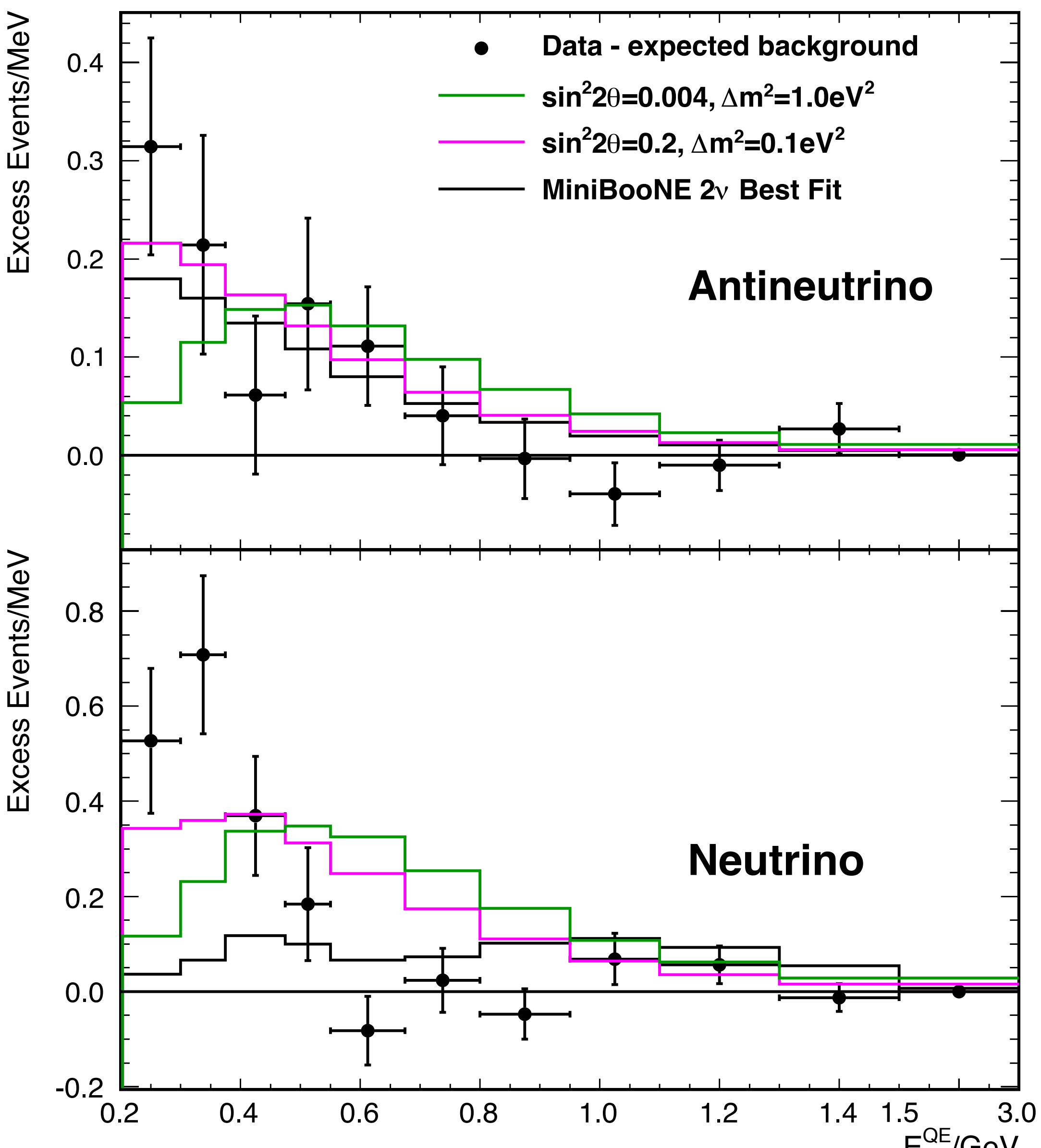
- The disappearance of neutrinos interacting via the neutral current is a strict probe of active-to-sterile oscillations.
    - No complicating contributions from active-to-active disappearance.
- Could definitively establish the existence of a sterile flavor, especially when considered in combination with charged-current based searches.

$$
\begin{aligned}
P(\nu_\alpha \to \nu_{\text{active}}) &= 1 - P(\nu_\alpha \to \nu_s) \\
&= 1 - \sin^2 2\theta_{\alpha s} \sin^2(1.27 \Delta m^2 L/E)
\end{aligned}
$$

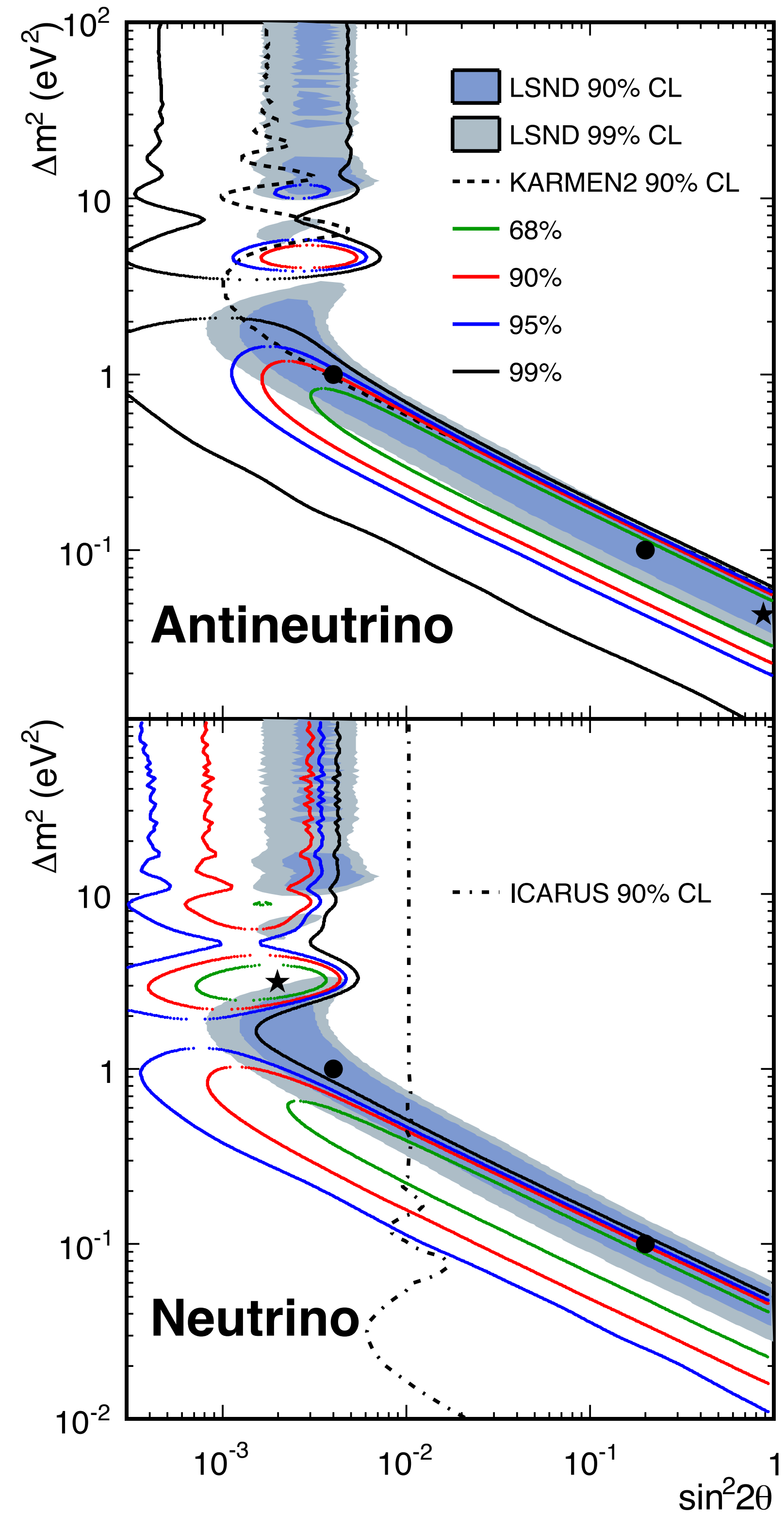
$$
\sin^2 2\theta_{\alpha s} = 4|U_{\alpha 4}|^2 |U_{s4}|^2
$$

MiniBooNE results

- MicroBooNE will be able to confirm or refute the low-E excess.
- What does this have to do with the sterile neutrino? It's not clear exactly. But, the low-E excess certainly drives the MiniBooNE anomaly.
- The low-E excess and the sterile neutrino are not the same because you have to consider all energy bins within a certain model (e.g. 3+1) when considering sterile neutrino sensitivity.



arXiv:1303.2588



High Energy Physics - Experiment

A Combined $\nu_\mu \to \nu_e$ and $\bar{\nu}_\mu \to \bar{\nu}_e$ Oscillation Analysis of the MiniBooNE Excesses

MiniBooNE Collaboration: A. A. Aguilar-Arevalo, B. C. Brown, L. Bugel, G. Cheng, E. D. Church, J. M. Conrad, R. Dharmapalan, Z. Djurcic, D. A. Finley, R. Ford, F. G. Garcia, G. T. Garvey, J. Grange, W. Huelsnitz, C. Ignarra, R. Imlay, R. A. Johnson, G. Karagiorgi, T. Katori, T. Kobilarcik, W. C. Louis, C. Mariani, W. Marsh, G. B. Mills, J. Mirabal, C. D. Moore, J. Mousseau, P. Nienaber, B. Osmanov, Z. Pavlovic, D. Perevalov, C. C. Polly, H. Ray, B. P. Roe, A. D. Russell, M. H. Shaevitz, J. Spitz, I. Stancu, R. Tayloe, R. G. Van de Water, D. H. White, D. A. Wickremasinghe, G. P. Zeller, E. D. Zimmerman

(Submitted on 19 Jul 2012 (v1), last revised 27 Aug 2012 (this version, v2))

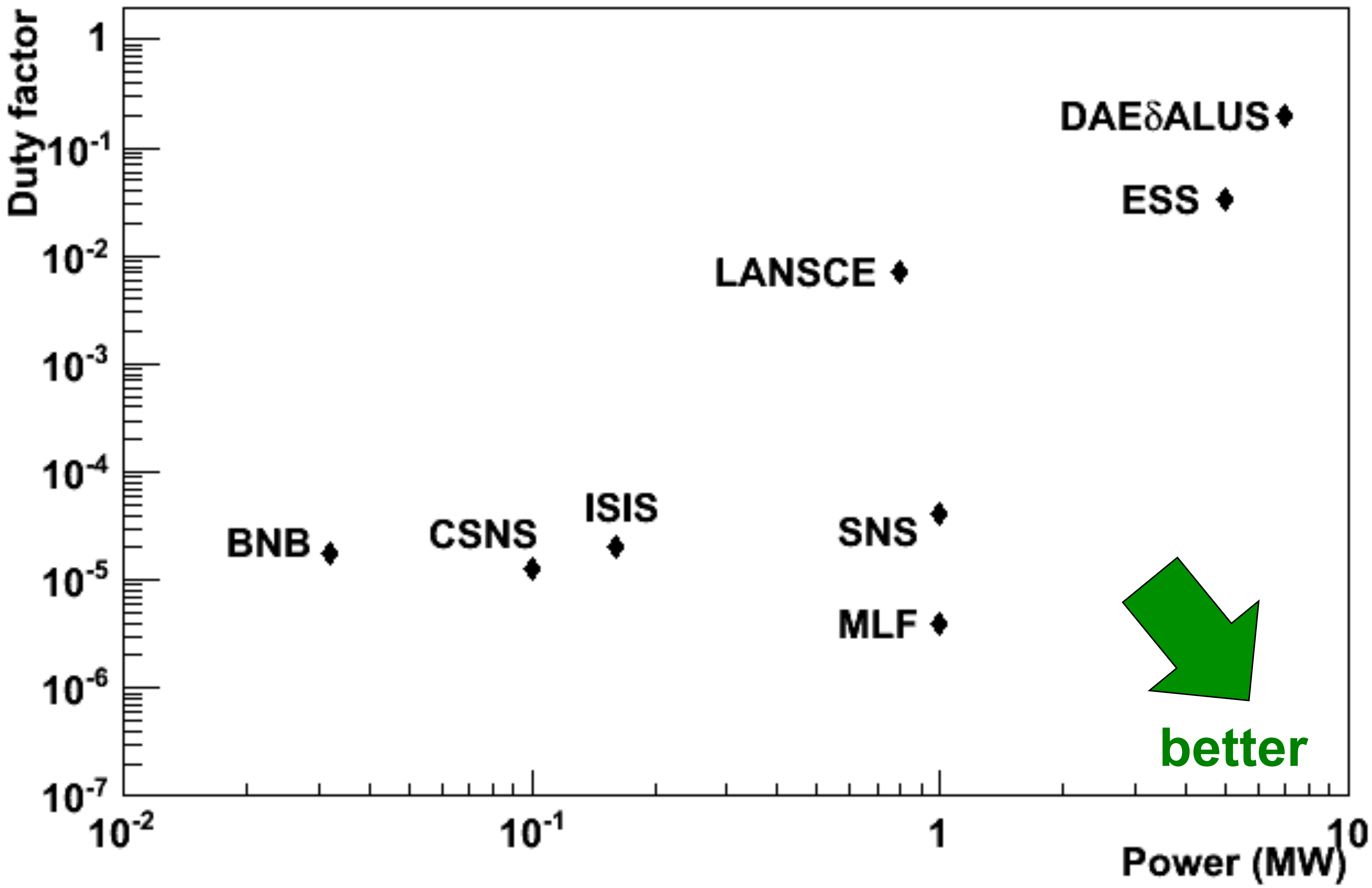
The MiniBooNE experiment at Fermilab reports results from an analysis of the combined ν_e and $\bar{\nu}_e$ appearance data from 6.46×10^{20} protons on target in neutrino mode and 11.27×10^{20} protons on target in antineutrino mode. A total excess of $240.3 \pm 34.5 \pm 52.6$ events (3.8σ) is observed from combining the two data sets in the energy range $200 < E_\nu^{QE} < 1250$ MeV. In a combined fit for CP-conserving $\nu_\mu \to \nu_e$ and $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations via a two-neutrino model, the background-only fit has a χ^2-probability of 0.03% relative to the best oscillation fit. The data are consistent with neutrino oscillations in the $0.01 < \Delta m^2 < 1.0$ eV^2 range and with the evidence for antineutrino oscillations from the Liquid Scintillator Neutrino Detector (LSND).

Comments:	Minor wording and figure changes and added references
Subjects:	**High Energy Physics - Experiment (hep-ex)**; High Energy Physics - Phenomenology (hep-ph); Nuclear Experiment (nucl-ex); Nuclear Theory (nucl-th)
DOI:	10.1103/PhysRevLett.110.161801
Report number:	LA-UR-12-23041; Fermilab-PUB-12-394-AD-PPD
Cite as:	**arXiv:1207.4809 [hep-ex]**
	(or **arXiv:1207.4809v2 [hep-ex]** for this version)

Submission history

From: William Louis [view email]
[v1] Thu, 19 Jul 2012 20:45:30 GMT (202kb)
[v2] Mon, 27 Aug 2012 14:08:52 GMT (264kb)

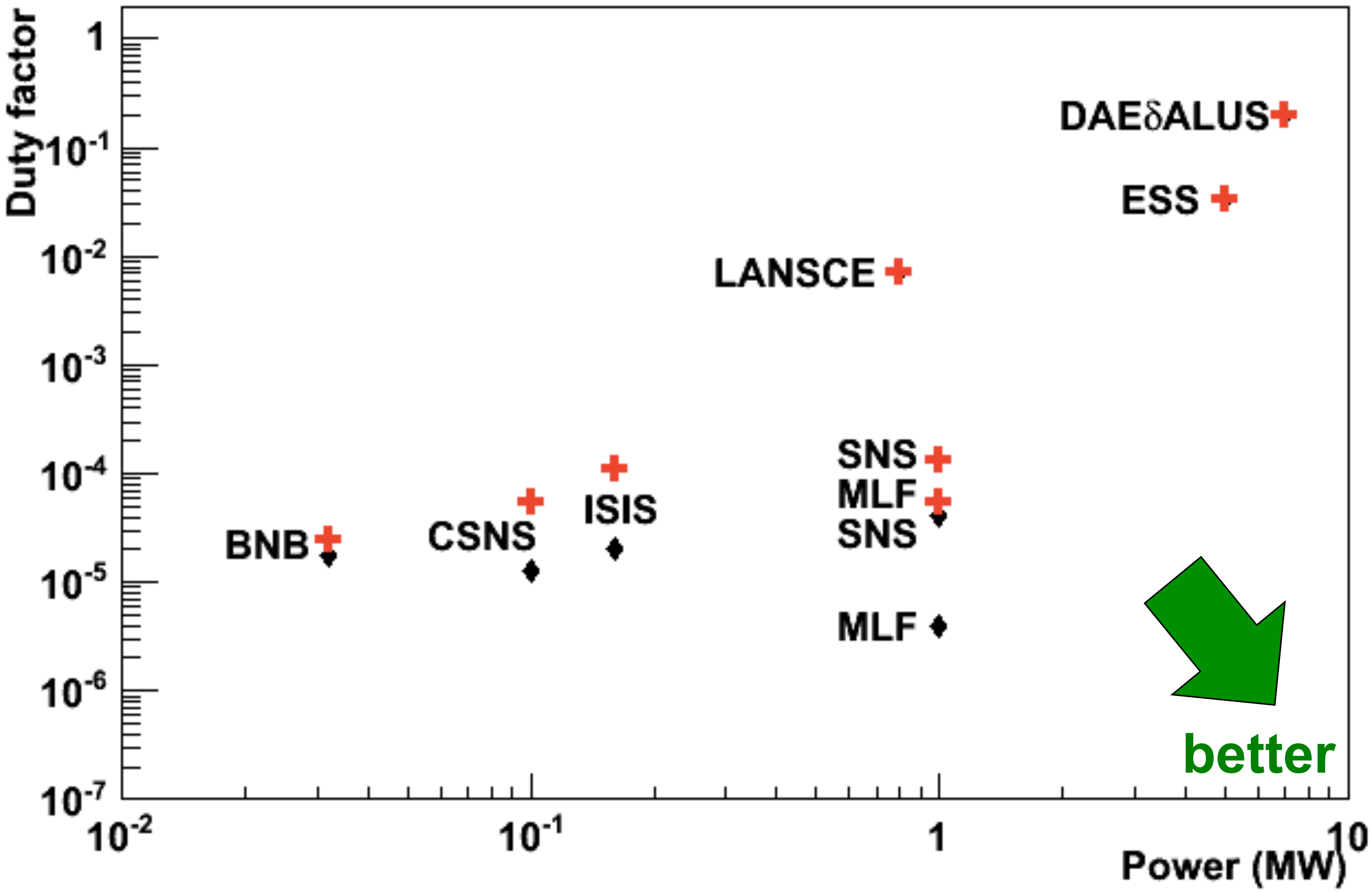
Flux $\propto$ power
Duty factor = T*rate (◆)



*Adapted from a slide by K. Scholberg

Flux $\propto$ power
Duty factor = T*rate (◆)
= max(T, 2.2 μs)*rate (+ for μdk ν's)

it doesn't help that much to be faster than μdk timescale



*Adapted from a slide by K. Scholberg

Of claims and sigmas

- Is a 5σ signal from a single experiment even good enough for discovery at this point? Maybe not. Indeed, the combination of two independent and reasonably “consistent” 3.8σ measurements (i.e. LSND and MiniBooNE) is certainly not good enough.

Experiment	Type	Channel	Significance
LSND	DAR	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	3.8σ
MiniBooNE	SBL accelerator	$\nu_\mu \to \nu_e$ CC	3.4σ
MiniBooNE	SBL accelerator	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	2.8σ
GALLEX/SAGE	Source - e capture	ν_e disappearance	2.8σ
Reactors	Beta-decay	$\bar{\nu}_e$ disappearance	3.0σ

MiniBooNE combo is 3.8σ

K. N. Abazajian et al. "Light Sterile Neutrinos: A Whitepaper", arXiv:1204.5379 [hep-ph], (2012)

- Do we need to see a wiggle? It would be nice. Unfortunately, much of the allowed (e.g. >10 eV^2) parameter space will not actually provide a discernible L/E wiggle in our experiments.

- We may have entered the dreaded “5σ from a single measurement is not good enough” phase, where quoting sensitivity in sigmas loses meaning fast.

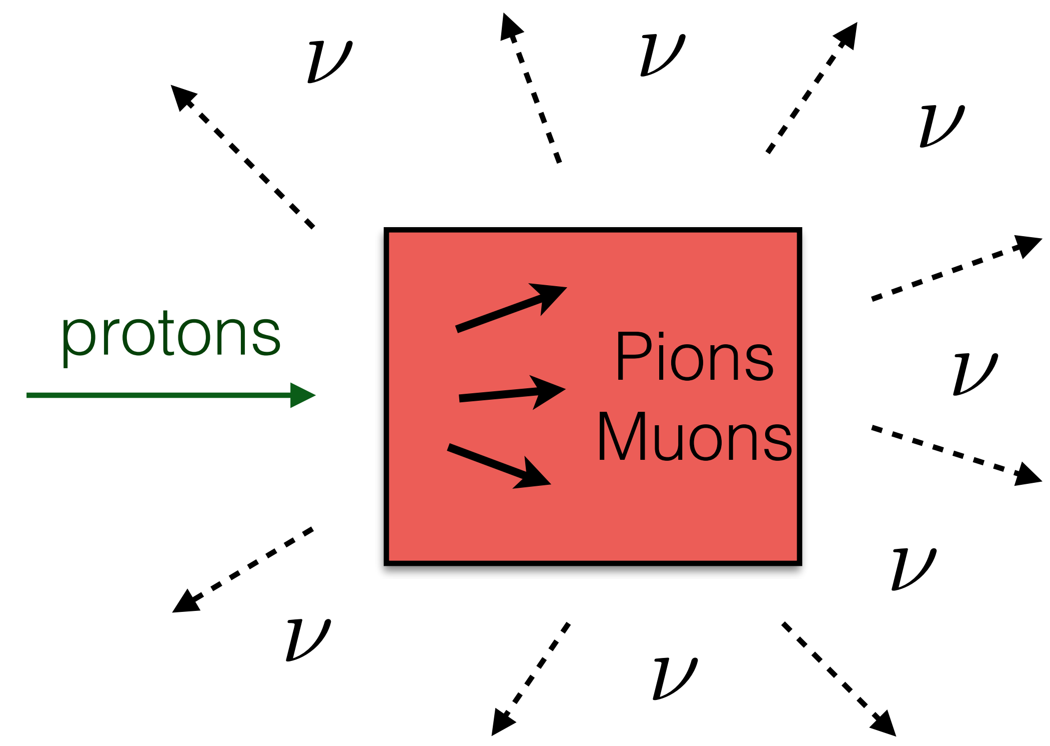
Clearly, an accelerator-based short baseline program is important to the community

From Snowmass 2013 Executive Summary on Neutrinos,
arXiv:1310.4340 [hep-ex]

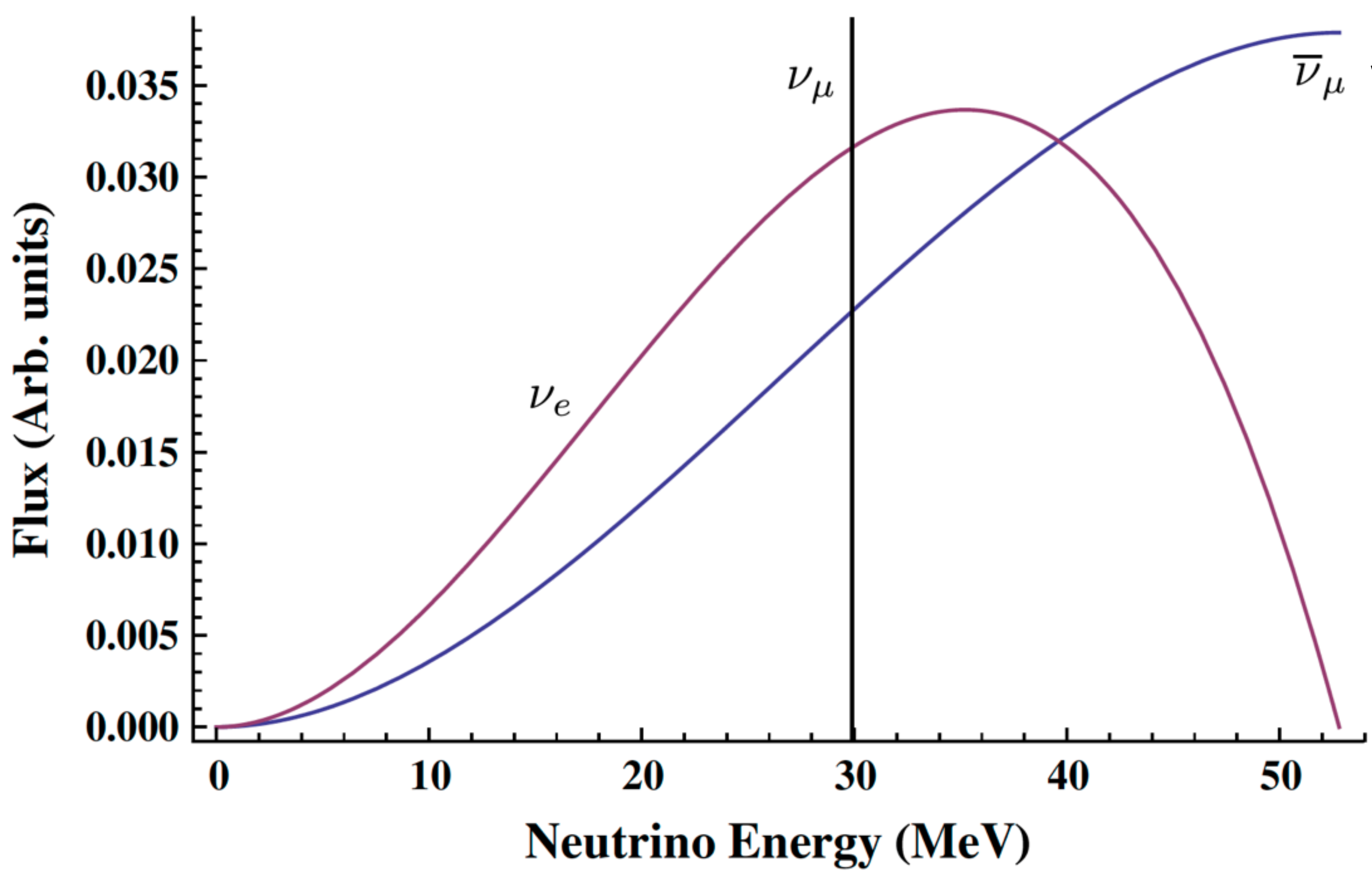
While these large, ambitious projects are vigorously developed, the following medium and small-scale neutrino activities need to be pursued.

- *Precision measurements and theories of neutrino cross sections and a detailed understanding of the neutrino flux from pion-decay-in-flight neutrino beams.* These activities can be pursued in the near- detectors associated with the large long-baseline projects or alongside R&D projects related to next-next generation neutrino beams, as well as by small-scale dedicated experiments. A well-considered program of precision scattering experiments in both low- and high-energy regimes, combined with a renewed dedicated theoretical effort to develop a reliable, nuclear-physics-based description of neutrino interactions in nuclei is mandatory. Scattering measurements may also be of intrinsic interest.
- *Definite resolution of the current short-baseline anomalies.* These will (probably) require neutrino sources other than pion-decay-in-flight and the pursuit of different flavor-changing channels, including $\nu_{e,\mu}$ disappearance and $\nu_\mu \to \nu_e$ appearance, using a combination of reactor, radioactive source and accelerator experiments. In addition to small-scale dedicated experiments, such experiments can be carried out as part of R&D projects related to next-next generation neutrino beams (e.g., nuSTORM, IsoDAR).
- *Vigorous pursuit of R&D projects related to the development of next-next generation neutrino experiments.* As discussed above, these medium and small experiments will also address several key issues in neutrino physics.

The LSND-style experiment



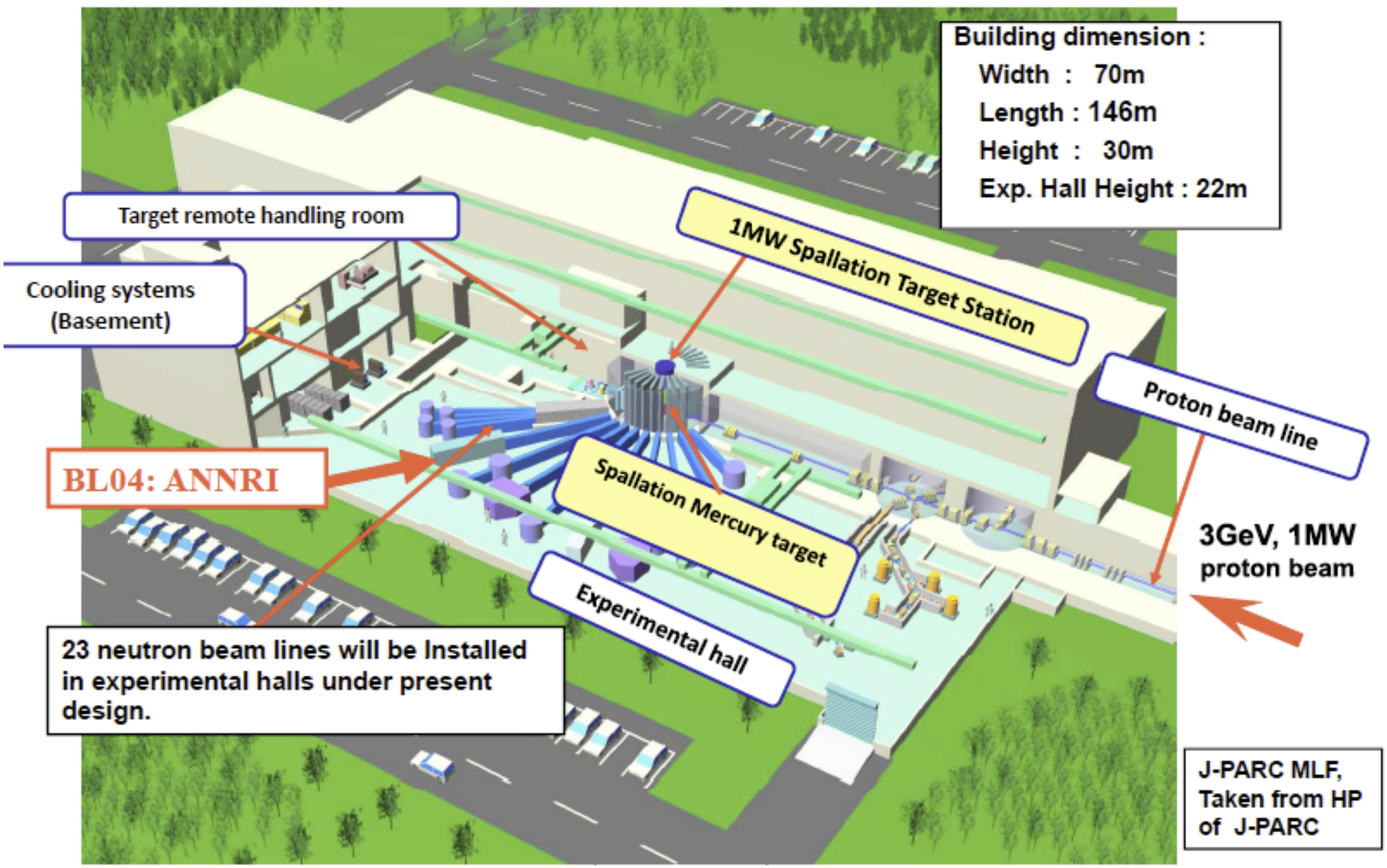
Neutrino flux from pion and muon decay-at-rest



$\overline{\nu}_\mu \to \overline{\nu}_e$?

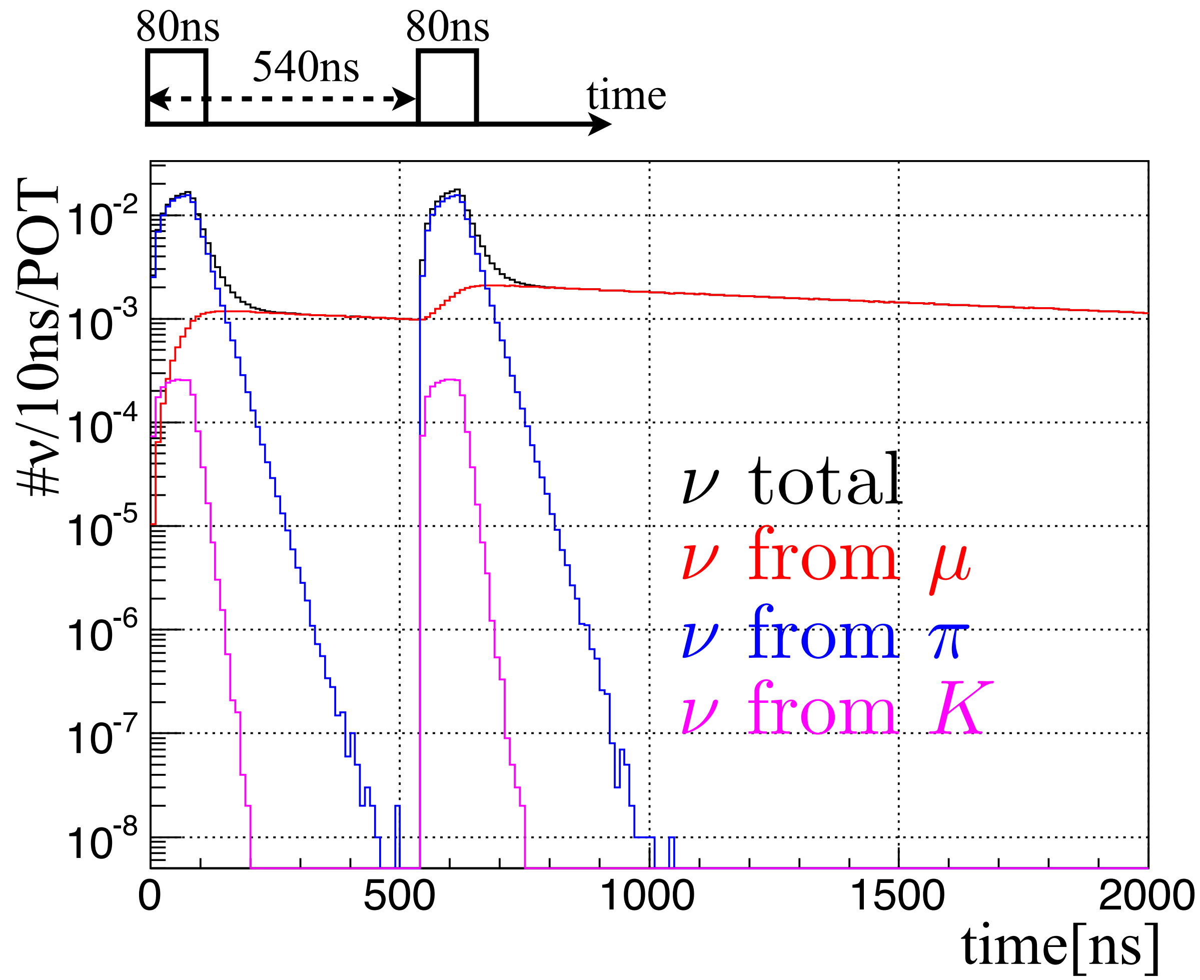
Neutr~~ons~~inos @ JPARC-MLF

J-PARC Materials and Life Science Experimental Facility



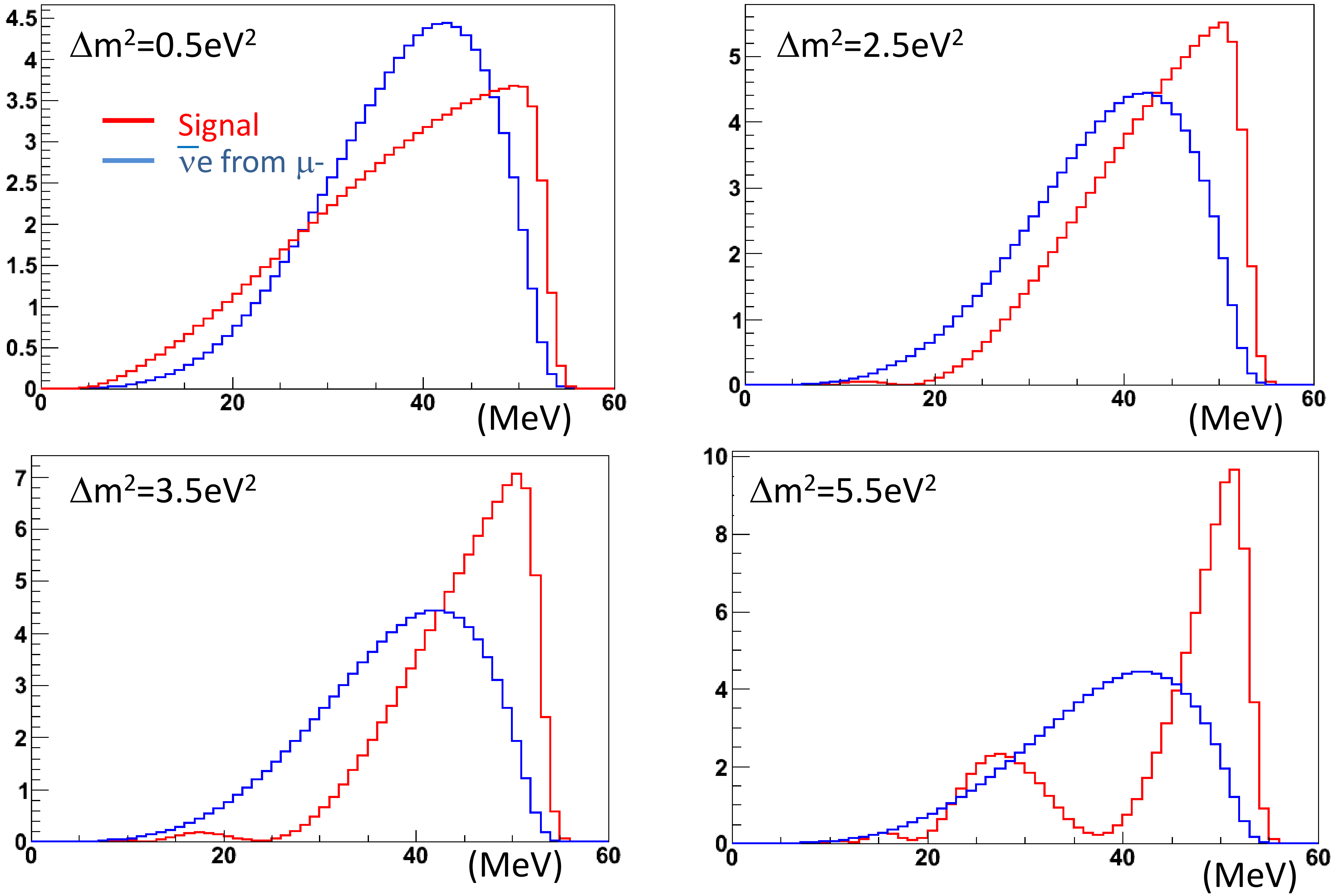
JPARC-MLF

	OscSNS	JPARC-MLF (phase 1)	Notes
Detector	800 ton	50 ton	
Baseline	60 m	17 m	
Cost	$20M	$5M	
Beam kinetic energy	1 GeV	3 GeV	pi+/pi- ratio is less favorable for JPARC-MLF
Beam power	1.4 MW	1 MW (eventually)	
Beam pulse	695 ns, 60 Hz	80 ns (x2), 25 Hz	Difference doesn't matter much due to muon lifetime



M. Harada *et al*, arXiv:1310.1437 [physics.ins-det]

A comment on the $\overline{\nu}_e$ intrinsic background for LSND-style



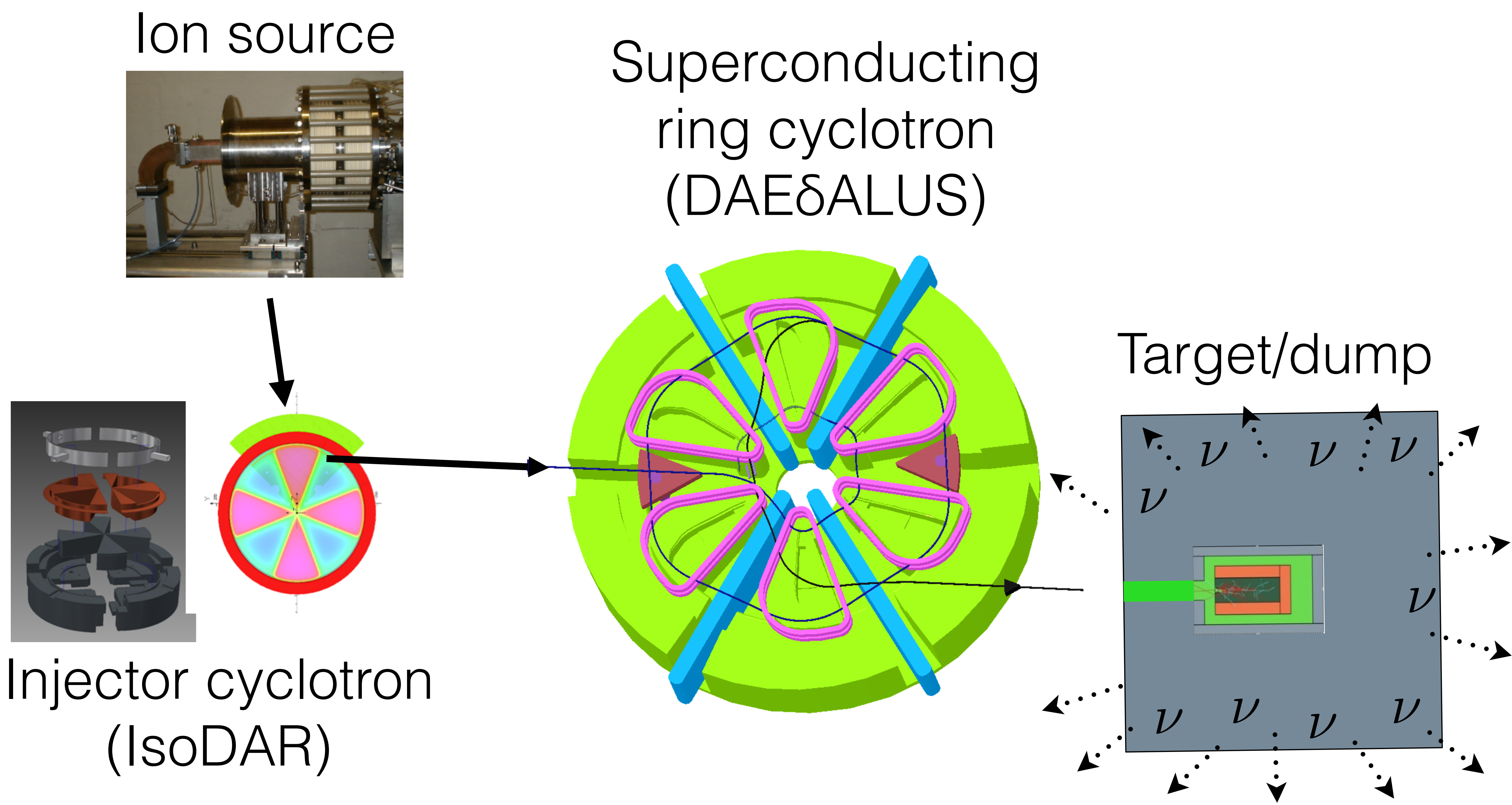
(plots are normalized by area)

M. Harada *et al*, arXiv:1310.1437 [physics.ins-det]

The DAEδALUS program

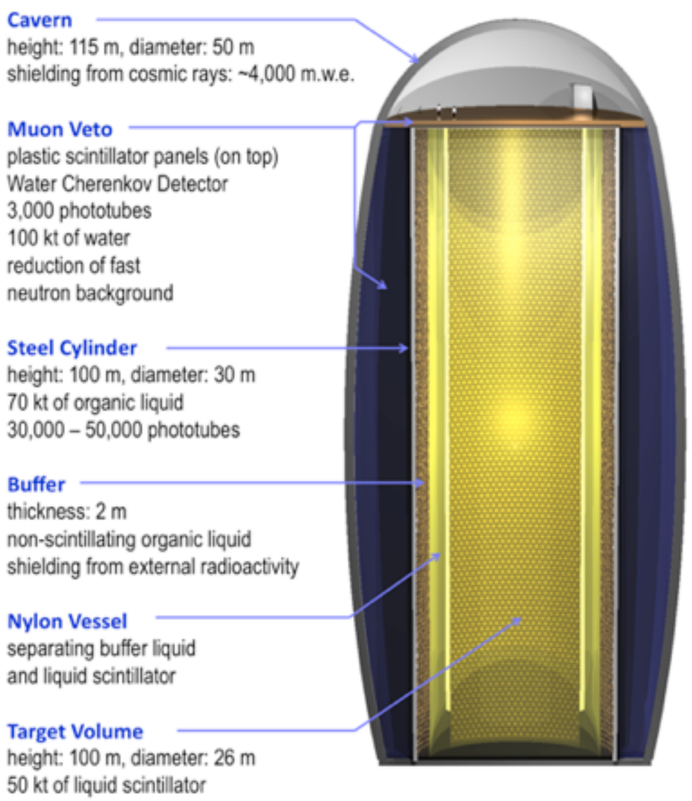
- The cyclotron as a new, intense source of decay-at-rest neutrinos.
  - High-Q isotope $$\boxed{{}^{8}\mathrm{Li} \rightarrow {}^{8}\mathrm{Be} + e^{-} + \overline{\nu}_{e}}$$
  - Pion/muon $$\boxed{\begin{array}{c} \pi^{+} \rightarrow \mu^{+}\nu_{\mu} \\ \mu^{+} \rightarrow e^{+}\nu_{e}\overline{\nu}_{\mu} \end{array}}$$
- Sterile neutrinos, weak mixing angle, NSI, δ_{CP}, v-A coherent scattering, supernova xsec, accelerator, …

The path to 800 MeV

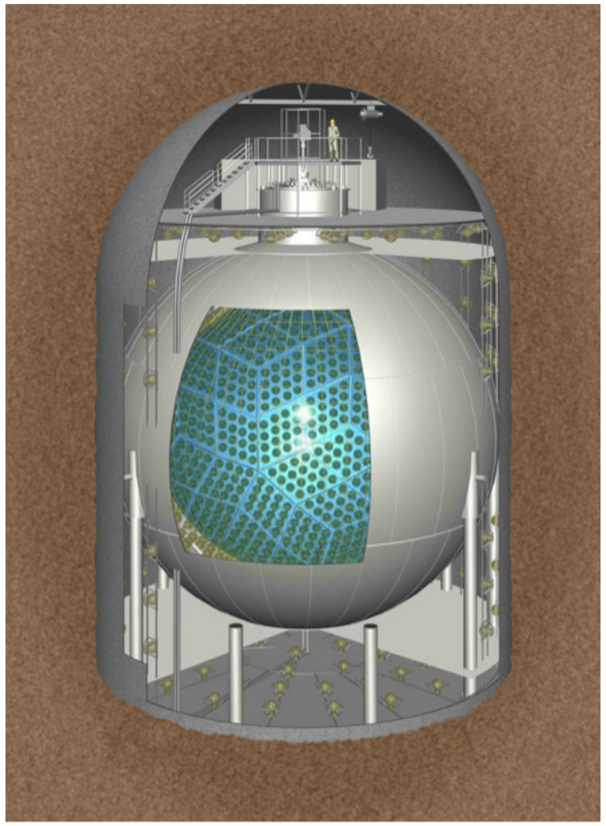


Where can IsoDAR run?

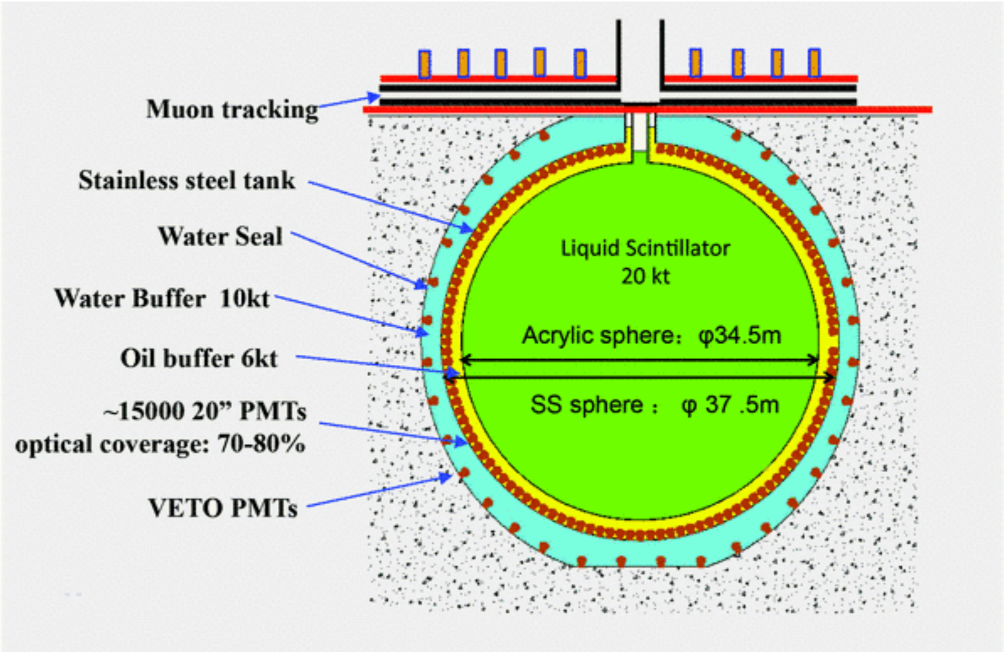
LENA



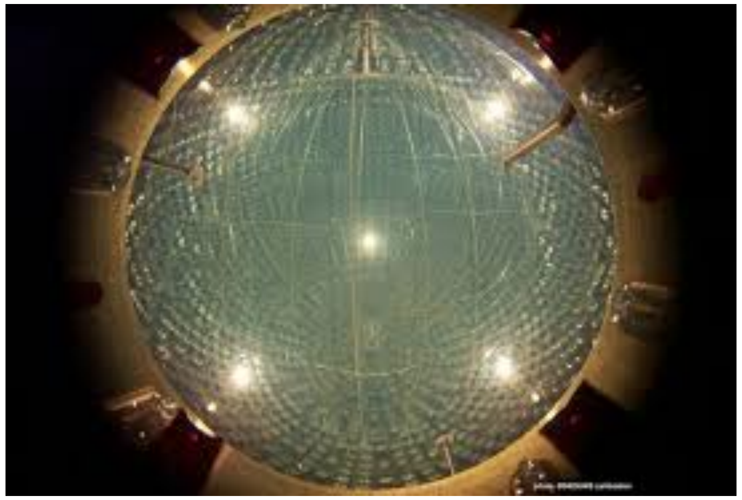
KamLAND



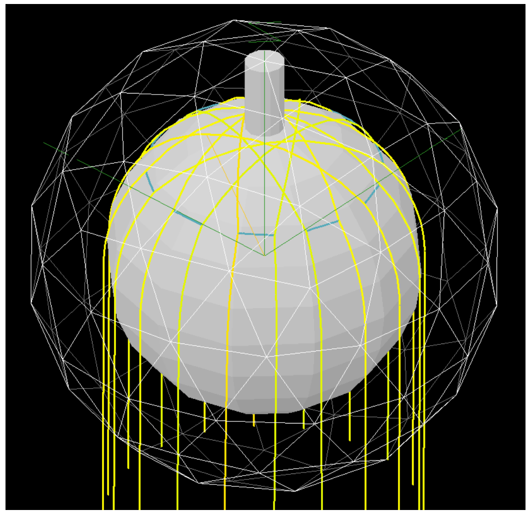
JUNO



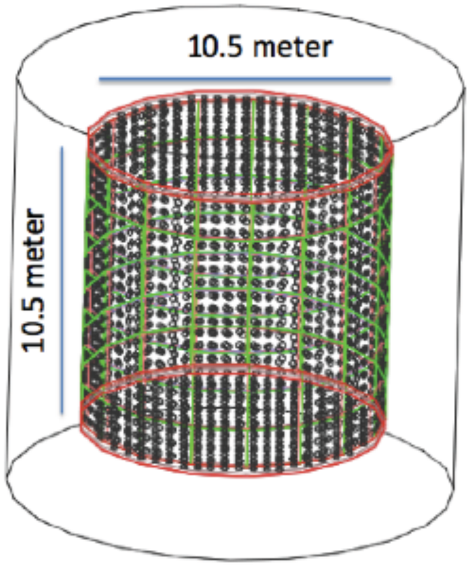
Borexino



SNO+



WATCHMAN



IsoDAR cost estimates at present

Cost-effective design options for IsoDAR
A. Adelmann et al. arXiv:1210.4454

1st source constructed -> $30M base cost (2013 $)

If more sources are constructed: $15M each

recommended contingency as of now: 50%
after first engineering design: 20%

DOE-sponsored study on a 2 mA proton machine

COST / BENEFIT COMPARISON

FOR

45 MEV AND 70 MEV CYCLOTRONS

MAY 26, 2005

Conducted for:

U.S. Department of Energy
Office of Nuclear Energy, Science, and Technology
Office of Nuclear Facilities Management
19901 Germantown Road
Germantown, MD 20874

Conducted by:

JUPITER
Technical, Security, and Management Solutions

Suite 900, Westfield North
2730 University Boulevard West
Wheaton, MD 20902

This is a simpler machine.

IsoDAR will cost more because the machine is larger…but this sets the scale.

EXECUTIVE SUMMARY

A cost/benefit study was conducted by *JUPITER* Corporation to compare acquisition and operating costs for a 45 MeV and 70 MeV negative ion cyclotron to be used by the Department of Energy in the production of medical radioisotopes. The study utilized available information from Brookhaven National Laboratory (BNL) in New York and from the University of Nantes in France, since both organizations have proposed the acquisition of a 70 MeV cyclotron. Cost information obtained from a vendor, Advanced Cyclotron Systems, pertained only to their 30 MeV cyclotron. However, scaling factors were developed to enable a conversion of this information for generation of costs for the higher energy accelerators.

Two credible cyclotron vendors (IBA Technology Group in Belgium and Advanced Cyclotron Systems, Inc. In Canada) were identified that have both the interest and capability to produce a 45 MeV or 70 MeV cyclotron operating at a beam current of 2 mA (milliamperes).

The results of our analysis of design costs, cyclotron fabrication costs, and beamline costs (excluding building construction costs) resulted in total acquisition costs of:

- $14.8M for the 45 MeV cyclotron, and
- $17.0M for the 70 MeV cyclotron.

Annual operating cost estimates for a 70 MeV cyclotron ranged between $1.9M and $1.1M; the large uncertainty is due to the lack of specificity in available data in comparing costs from BNL and the University of Nantes.

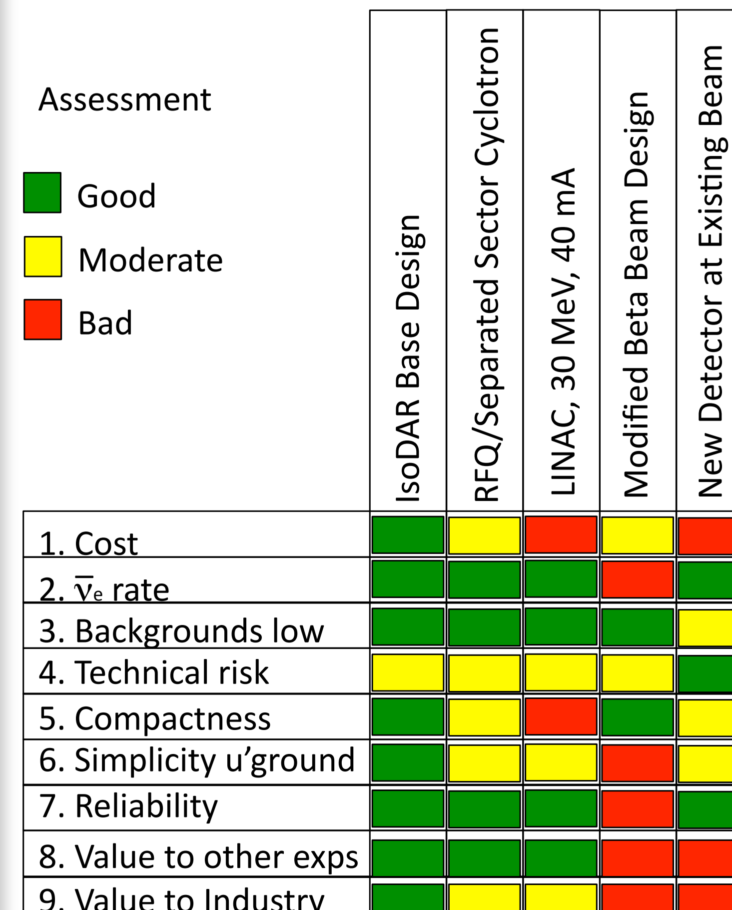
Overall power requirements (exclusive of facility heating and air conditioning) were estimated to be:

- 560 kW for the 45 MeV cyclotron, and
- 831 kW for the 70 MeV cyclotron.

Operational lifetime is expected to be in excess of 30 years for the main components of the accelerator.

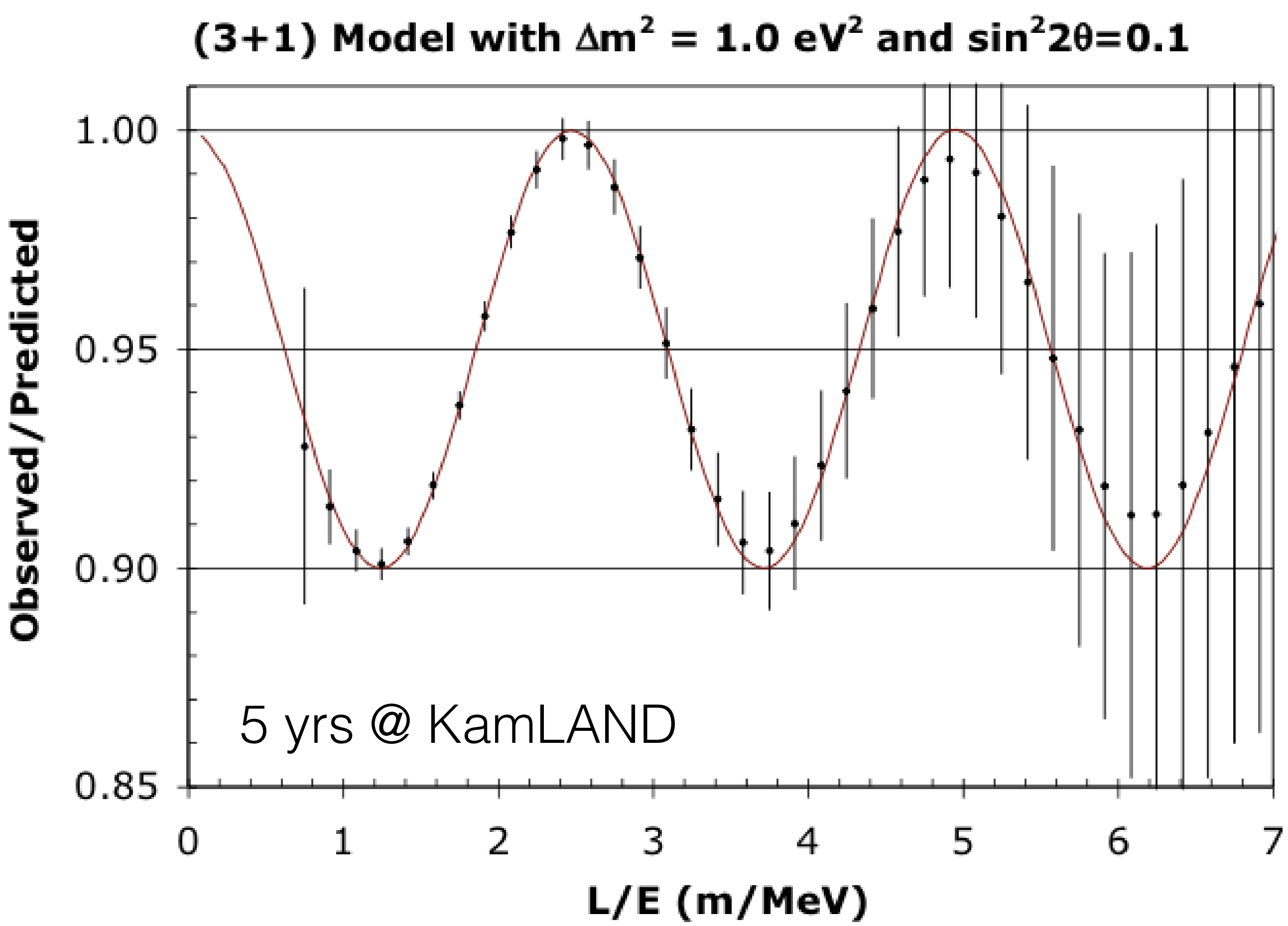
Considerable scientific and economic benefits are gained in using the 70 MeV cyclotron compared to use of the 45 MeV cyclotron in terms of the variety and quantity of isotopes that can be produced. Selected examples of benefits in isotope production are discussed.

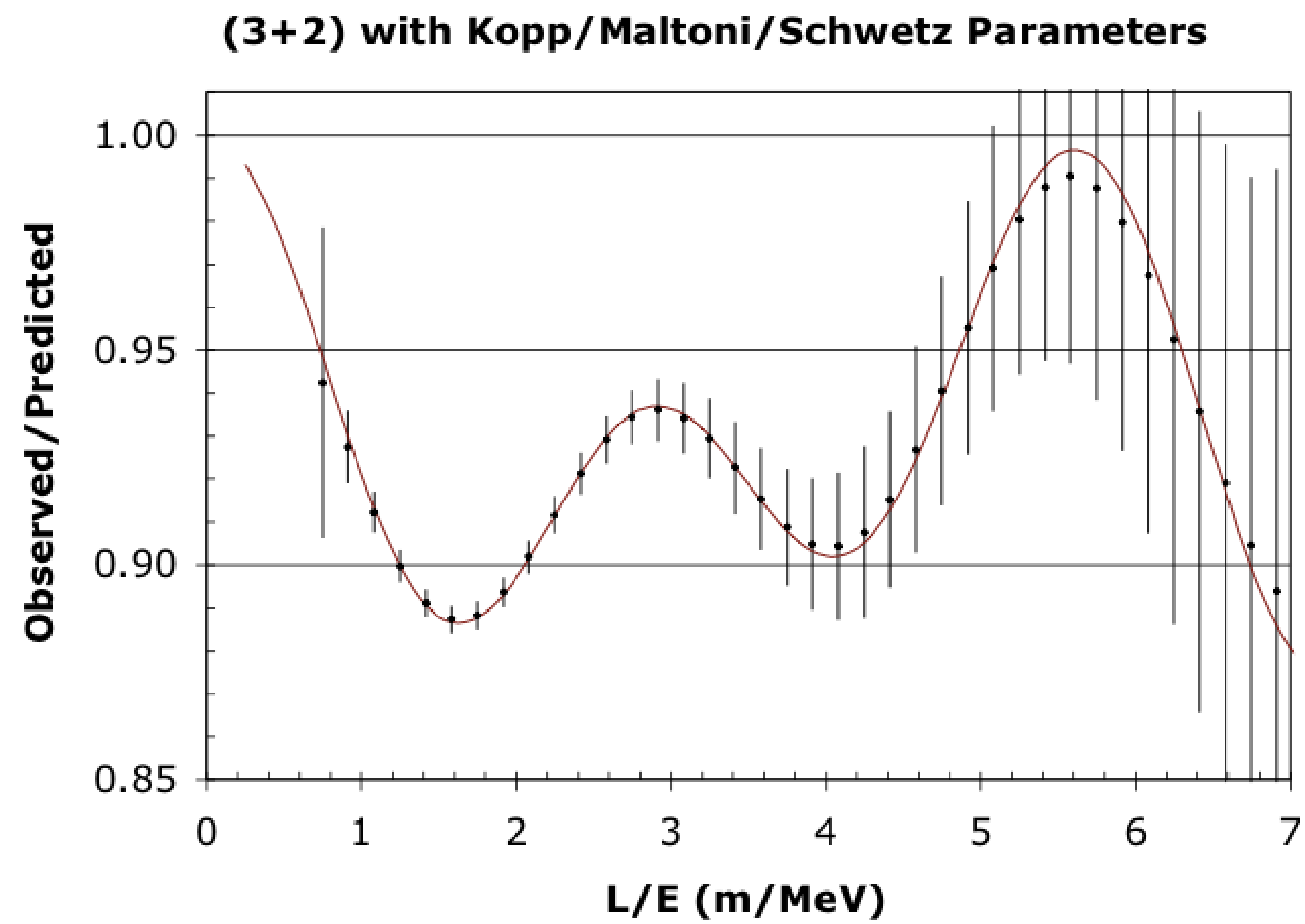
Other options?



How many steriles?

Observed/Predicted event ratio vs L/E, including energy and position smearing





IsoDAR's high statistics and good L/E resolution provide the potential for distinguishing (3+1) and (3+2) oscillation models